Enhancing monitoring capabilities at Nevado del Ruiz volcano, Colombia, and its magma system inferred from seismic waveform analyses

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Nevado del Ruiz volcano located in the Colombian Andes continues its eruptive activity. To enhance monitoring capabilities at this volcano, broadband seismometers and other equipment were installed by the Science and Technology Research Partnership for Sustainable Development (SATREPS) project in Colombia. Using waveform data from the seismic network, source locations of volcano-tectonic (VT) earthquakes, very-long-period (VLP) events, and tremor were systematically determined by the automated amplitude source location (ASL) system. We also performed tomographic inversion of *P* and *S*-wave arrival times and waveform inversion of VLP events. In this paper, we describe the seismic network and monitoring system at Nevado del Ruiz. We then discuss the magma system beneath this volcano based on our estimated source location distributions, tomographic images of *P* and *S*-wave velocities, and source mechanisms of VLP events.
At Nevado del Ruiz volcano, 12 broadband and 3 short-period seismic stations are maintained. Realtime waveform data are retrieved by the seedlink system. We use an automated event trigger system using seismic amplitudes in a low-frequency band of 0.3-1 Hz. Source locations of triggered events and tremor are automatically determined by the ASL system using high-frequency (5-10 Hz) seismic amplitudes. The estimated source information is accessible through a web system, and manual ASL analysis can be performed by this web system.
Our ASL results indicated that VT earthquakes occurred beneath the northern and southern flanks and the sources of tremor and VLP events were distributed from the summit crater (5311 m) to a depth of about sea level in the NW direction. We found that some tremor episodes showed moving sources along the tremor and VLP source region. Our waveform inversion of VLP signals points to tensile cracks dipping toward the NW direction. Tomographic inversion images displayed that the tremor and VLP source region corresponds to the region with high V_p/V_s ratios, implying the existence of fluids in this region. These results suggest that this source region represents an active crack-like conduit, in which tremor and VLP events were triggered by magma fragmentation processes.

Temporal variations in the resonator size and fluid properties of LP events at Kusatsu-Shirane and Galeras volcanoes

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The fluid-filled crack model has been considered as a model of the resonator at the source of long-period (LP) seismic events. Crack geometry and fluid acoustic properties have been estimated by the comparison between observed peak frequencies of LP events and resonance frequencies of the crack model. Recently, an analytical formula for the resonance frequencies of the crack model was proposed by Maeda and Kumagai (GRL, 2013; GJI, 2017). Taguchi et al. (AGU meeting, 2016) showed that observed several peak frequencies in LP events at Kusatsu-Shirane and Galeras volcanoes were successfully explained by those predicted from the analytical formula. In this study, we further analyzed LP events at both the volcanoes, and systematically estimated the crack model parameters at the LP sources using the analytical formula, in which we assumed misty and dusty gases at Kusatsu-Shirane and Galeras, respectively. Our estimates indicated that the crack geometry and fluid properties largely changed in our analysis period between August 1992 and January 1993 at Kusatsu-Shirane and that between 6 and 10 January 1993 at Galeras. We found that the crack volume increased with increasing gas-weight fraction at both the volcanoes. Although an increase in gas-weight fraction was indicated by Kumagai et al. (JGR, 2002) at Kusatsu-Shirane within our analysis period, our estimates indicated that the significant volume increase (from 10^{-1} m^3 to 10^3 m^3) was associated with the gas-weight fraction increase. At Galeras, we found that the crack volume systematically decreased with decreasing gas-weight fraction. An eruption occurred several days after the LP activity analyzed in this study. Our estimated trend may be caused by precursory processes leading to the magma eruption. This study demonstrates that the approach using the analytical formula is useful to constrain the source process of LP events and to diagnose the state of fluids in magma and hydrothermal systems.

Woodpecker seismicity before the flank effusive eruption at Stromboli

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Stromboli volcano in Italy is known as persistent eruptive activity (Strombolian eruptions). Its activity shifted from summit eruption to flank lava effusion in the Sciara del Fuoco on 7 August 2014. We obtain continuous seismic data during the transition from Strombolian activity to the lava effusion. In this presentation we report unusual seismic waves, that is particularly observed from 22 July until the onset of flank eruptions. The unusual waveforms were looked like repeating volcanic tremor. The tremor (single wave packet) is composed of numerous repeating pulses of 4-12Hz, that having almost same amplitude. It continues for several to ten minutes, and then disappears with some large pulses (or one large pulse). Since the characteristic waves appeared repeatedly with a short pause time of a few minutes, we call this seismic activity as “woodpecker seismicity”. Individual pulses that make up the woodpecker seismicity are very similar. They are likely to be repetitions of the same event. To investigate the waveform similarity, we extract waveform containing an arbitrary pulse as a template event and calculate coefficient of correlation with continuous data every one sample. We set lengths of template events two seconds. As a result, it was found that the emergence of a pulse can be identified based on correlation coefficient for any period of the woodpecker seismicity. Similar results were obtained by changing the template. Since the woodpecker seismicity was seen in the period preceding the flank effusive eruption, the woodpecker seismicity may have the relationship with the dyke intrusion. To check the temporal change in the hypocenter location of the woodpecker seismicity, we investigate the temporal fluctuation of time difference of correlation peaks at the two different stations (RFR, PZZ). As a result, it was found that the time difference at which the correlation coefficient reached the maximum was quite stable at both stations. From this fact, it seems that the mechanism and location have not changed. Considering the activity period, we expect that the woodpecker seismicity reflects some changes in volcanic process below the crater towards the flank eruption. We are planning to investigate the relationship between the woodpecker seismicity and the very long period (VLP) events that is constantly occurring.

Keywords: Stromboli volcano, woodpecker seismicity, transition process of volcanic eruption

Harmonic Tremors at Shinmoedake

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Background

During the 2011 eruptions, both seismic harmonic tremors (ground oscillations) and acoustic harmonic tremors (air oscillations) were observed at Shinmoedake. Here we report the behavior of the time evolution of the frequency spectrum as well as the phase portraits of the harmonic tremors, providing evidence for a non-linear plumbing system at Shinmoedake.

Data

We utilized seismographs from 4 broadband seismometers located within a radius of about 3 km around Shinmoedake. Spectrograms and power spectral density methods were used to track the changes in the peak frequencies over time. Additionally, phase portraits of displacement with respect to velocity were obtained to further illustrate the change in properties of the non-linear mechanism of the harmonic tremors.

The first seismic harmonic tremor was observed shortly after 17:00 on 2011/01/30, and similar seismic harmonic tremors occurred sporadically until 2011/01/31. The seismic harmonic tremors during this time frame had obvious but indistinct harmonic frequency peaks which fluctuated and drifted over time. The fundamental peaks were noted to fluctuate about the values of 0.9 Hz, 1.05 Hz or 1.3 Hz. The first seismic and acoustic harmonic tremor occurred at 21:49 on 2011/01/31 with a clear and distinct fundamental peak at 1.5 Hz and higher overtones starting from 3 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a single loop.

On 2011/02/02, the longest seismic and acoustic harmonic tremor occurred over a time frame of 40 minutes from 20:43 to 21:23. The fundamental peak was located at around 0.9 Hz with clear higher overtones at 1.8 Hz, 2.7 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a double nested loop.

On 2011/02/03, a series of sporadic, short seismic and acoustic harmonic tremors occurred over a time frame of 35 minutes from 13:24 to 13:59. The fundamental peak was located at around 1.7 Hz with higher overtones starting from 3.4 Hz and so forth. The phase portrait of particle displacement and velocity during this time frame shows a single loop.

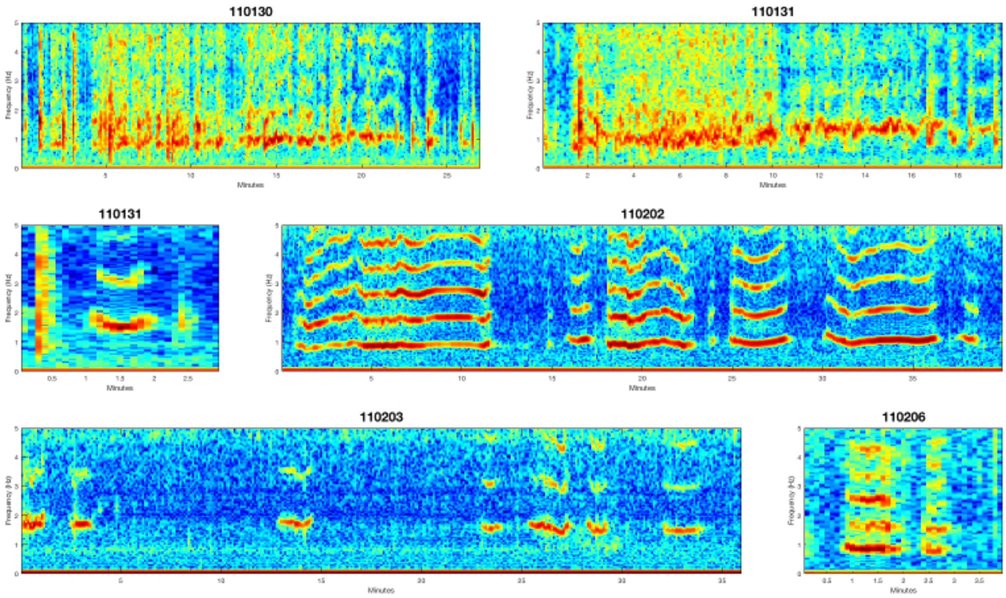
On 2011/02/06, a short seismic and acoustic harmonic tremor occurred over a time frame of just 2 minutes from 12:00. The fundamental peak was located at 0.9 Hz with clear higher overtones at 1.8 Hz, 2.7 Hz and so forth. Together with the returning of the fundamental mode to 0.9 Hz, the phase portrait of particle displacement and velocity during this time frame also shows a double nested loop.

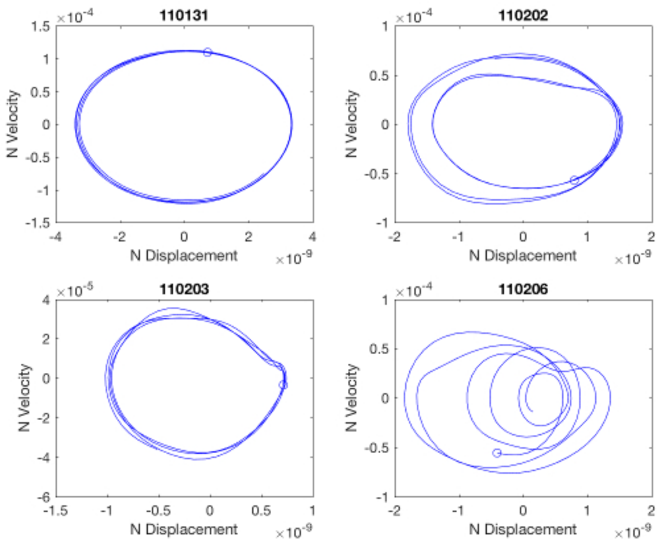
Discussion

We interpret the jumps in frequency of the fundamental peak of the seismic acoustic harmonic tremor from 1.5 Hz to 0.9 Hz, to 1.7 Hz and back to 0.9 Hz as period doubling of a non-linear system rather than a change in physical dimensions of a resonant cavity. This period doubling is due to parameter change in the non-linear system describing the volcanic conduit, resulting in a bifurcation of the non-linear system.

We note that this observational result is supported theoretically by a lumped parameter model of non-linear excitation by fluid flow through a channel (B. R. Julian, 1994). Therefore, we treat this as evidence that the harmonic tremors at Shinmoedake are a result of non-linear fluid flow through the volcanic conduit rather than a resonance effect.

Keywords: Harmonic Tremors, Shinmoedake





Conduit opening process toward ash eruptions estimated from continuous tremor at Aso volcano: ash eruptions in May 2011 and in January 2014

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Continuous volcanic tremor at Aso volcano, has a feature to vary in amplitude with volcanic activity. Takagi et al. (2009) revealed that the source location of the continuous tremors was different between a calm and an active period. However, it has not yet been clarified about path and timing of the source migration, and relationship between the source location and occurrence of eruptions.

Ash eruptions occurred on May 15, 2011 and January 13, 2014 at Aso volcano (Japan Meteorological Agency 2011, 2014). Preceding both the eruptions, vents opened in the center of the crater bottom, 5 and 11 days before the 2011 and 2014 eruptions. Amplitude of continuous tremor increased before the opening of the vents and then decreased after the opening. While no significant change in the tremor amplitude was observed before the 2011 eruption, the amplitude gradually increased before both opening another vent and an eruption on January 13, 2014.

In this study, we estimated source location of the continuous tremor in these two eruption event periods. Then, we infer processes in a conduit system toward the eruptions. We use the vertical seismic records at five permanent stations around the active crater. The source location was estimated by a grid search technique using spatial distribution of the observed tremor amplitude (e.g. Battaglia & Aki, 2003). In this calculation, 1-D seismic velocity structure (Sudo & Kong, 2001; Tsutsui et al., 2003) and Q=40 were used. The quality factor was determined by an inversion method using t^* value (De Gori et al., 2005).

As a result of our estimation, in both the 2011 and 2014 event periods, the source locations of the continuous tremor are distributed in a cylindrical space beneath the crater. They are ranging between a depth of 400 m and the crater bottom. The distribution of the tremor source locations should indicate the shallowest pathway in the conduit system at Aso volcano. This pathway connects the crack-like conduit (Yamamoto et al., 1999) and the crater bottom distribute, through the hydrothermal fluid reservoir at a depth of 50-300 m (Kanda et al., 2008).

Another finding of the estimation is that the source location varies with changes of the activity. Before the significant increases of amplitude in 2011 and in 2014, the tremor is radiated at a 200 m depth. The source depths of the tremor with increasing amplitude before the opening the vents are different between these events, 100 m in 2011 and 200 m in 2014. This is thought to indicate processes of establishing the fluid pathway at <200 m depths, which finishes when the vent has opened with drop of amplitude. The source location has migrated to 200 m shallower region until <10 days before the ash eruptions in the both events. This source migration may be caused by processes leading the eruptions, without change of amplitude.

Based on the temporal variation in the observed amplitude and the estimated source depth of continuous tremors, we specular processes in the shallowest part of the conduit system in the 2011 and the 2014 events. Fluid supply into the pathway had increased from March 2011 and then fluid pressure in the pathway increased. This led the pathway at a 100 m depth was widened with significant increase in tremor amplitude. Due to opening the vents, the amplitude decreased sharply on May 10. After that, the tremor source ascended. When the source reached at the crater bottom, on May 15, the ash eruption occurred. After that, the activity was once ceased by rainfall. From December 2013, the fluid supply had increased again. Then, the pathway was expanded at a 200 m depth. After the opening of the vent on January 2, 2014, the tremor source ascended to a 200 m depth. At this time, the small-scale pathway expansion also proceeded. As the shallower pathway than the depth 200 m had already been established, the source depth may jump to the near of the crater bottom. On January 13, the other vent was opened and the ash eruption occurred.

Keywords: Aso volcano, volcanic tremor, ash eruption, conduit system

Stress response of volcano-tectonic seismicity - tidal response (2)

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After the historical discovery that an abrupt increasing the seismicity was followed by the eruption at Usu volcano in 1910, volcanic seismicity is recognized to be one of the most reliable observations to predict volcanic eruptions. The seismicity prior to eruptions has many temporal patterns. In some cases, seismicity increases divergently just before the eruptions, and it has a quiescence in a few days before eruption in the other cases. The relation among the observed seismicity and physical conditions inside of volcanoes is still unsolved even the volcanic seismicity is well operationally used for hazard estimation of volcanic eruptions. Induvial earthquake may be partly controlled by accidental effects because it is caused by fracture of the rock. However, seismicity is a statistical value, and it thought to have a robust information to present the condition inside of volcanoes. We studied the relation among stress rate and seismicity change around volcanoes based on rate and state friction (RSF) law proposed by Dieterich (1994), and found out that the seismicity can be well explained by the law in the case of the stress changes by magma storage as well as ones by the great earthquake far from volcanoes. Furthermore, we found tidal response of volcanic seismicity at Izu-Oshima volcano. In this presentation, we will present the results of statistical test and tidal response changed in 2013.
Schuster’s test is well used for testing the tidal response of seismicity. It is based on the 2D random walk theory. Firstly, we use this test to demonstrate the seismicity correlate with earth and ocean tide. In this method, absolute value of stress generated by tide is not considered and we applied chi-square test as follows. Bins of tidal stress value is dived as that each bin has the same time interval of tidal stress ranges, the number of earth quakes in each bin (stress range) should be show Poisson’s distribution. Whether earthquakes occur randomly or not can be checked by chi-square test.
As mentioned before, we checked the volcanic earthquakes occurring at shallow region beneath Izu-Oshima caldera during 2004 and 2016. The null hypothesis that the earthquakes occur randomly are rejected with high confidence for the earthquakes occurring after 2013, but it cannot be rejected earthquakes before 2012. Supposing various focal mechanisms for the earthquakes, the result is not changed because the normal stress component acting on fault surface is dominant. Therefore, we tentatively use the volumetric tidal stress, that is equivalent to pressure acted on the fault planes. The earthquakes after 2013 occurred when the tidal volumetric stress is near the local maxima (extension). It means that earthquakes prefer to activate in maximum condition of the Coulomb failure function.
We will discuss that temporal change of tidal response of the seismicity. At very active volcanic zone of ocean bottom in West Pacific Rise, seismicity increased when tidal volumetric stress becomes local maxima distinctly (Stroup at al., 2007). In fact, as decreasing effective normal stress acting on the fault plane becomes low, the tidal response of seismicity becomes distinct and earthquakes prefer to occur in maximum extensional tidal stress. We have found out that the volcanic earthquakes at shallow occurring beneath Izu Oshima caldera, are affected by stress changes generated by magma storage in the reservoir located at the depth of 5km. And the seismicity after 2011 was greater than the expected value calculated using RSF model. The both fact show that the effective normal stresses at fault planes decreased in 2011 or 2013, and kept low value until the present. One of the most feasible reasons of the low effective normal stress is increasing pore pressure beneath the hypocenter zone located just above estimated pressure source of magma reservoir.
Izu Oshima volcano repeats eruptions every 30-40 years, and latest eruption occurred in 1986. It passed over 30 years. The above observations probably caused by uprising of volatile component from magma

reservoir, and it makes the pore pressure at the hypocenter zone increases, and decrease effective normal stress on the fault planes of the volcanic earthquakes after 2011 or 2013. This is one of the possible precursory phenomena of next volcanic eruption. And we would like to exaggerate the volcanic seismicity is very sensitive to stress in this case.

Keywords: volcano-tectonic earthquakes , seismicity, tidal response, active volcano, volatile component

Brief overview of landing survey and seisimic observation at Nishinoshima

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A new volcanic islet had been growing up with lava effusion and Strombolian acitivities at Nishinosima, Izu-Bonin arc from November 2013 to November 2015. The morophological evolution of Nishinoshima had been revealed based on airbone observtions and satellite images. The eruption activity has been monitored continuously using ocean bottom seismograph observation; the number of eruptions had registered a decline gradually, the eruption having stoped by the end of November 2015. After the volcanic activity falling to a low level, we had promoted a research survey of volcanology and bionomy at Nishinoshima from October 16th to 25th, 2016, using an academic investigation ship "Shinsei-maru" managed by AORI, University of Tokyo. The investigation item of the landing team were geological survey, installation of seismic station, and survey on nidification of seabirds. OBSs and OBEMs had been installed around Nishinoshima, pre-installed OBSs having recoverd. A monitoring system of remote volcanic island using WaveGlider was operated around Nishinoshima on a trial basis. An analysis of whole rock chemical composition of volcanic products in 2013-2015 eruption reveals that all samples are composed of andesite with SiO_2 content of 59.5-59.9wt%, falling on middle content between the eruption products in 1973-1974 eruption and the laval of the old islet. The telemetric seismic monitoring system in Nishinoshima is on couse to operate; the seismic data occasionally include long-lasting high-frequency tremors which seem to be related with some sort of Nishinoshima activity. We will make clear the growing process of volcanic islet together with geological and geophysical knowledges based on futher analyses of volcanic products and those of OBS and OBEM data which will be recovered on June 2017.

Keywords: Nishinoshima, volcanic islet, eruption

Geology and eruptive process of new Nishinoshima, Ogasawara, Japan, revealed from first landing and survey of eruptive products

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The island-forming eruption at Nishinoshima volcano, Ogasawara Islands, Japan, began its activity in November 2013 and ended in late 2015. During the KS-16-16 cruise in October 2016, we landed on Nishinoshima for the first time since the beginning of the eruption, and studied geological features of the new island. We approached and landed the western coast of the island where the pre-existed island remains partially. Along the gravelly coast, we observed many lava lobes that were emplaced during the different eruption periods between early 2014 and mid 2015. The periods of lava emplacement were determined based on aerial photos and satellite images. The front of lava lobe (a few to >10 m thick) is generally eroded by wave action and exposed its interior. The lava lobes consist of a black or dark gray, glassy clinker part and a massive inner part, some of which are highly fractured, vesiculated, and/or oxidized. Rubbly lava surface was commonly observed. The top of pre-existed island is covered by ash and scoria fallouts with thickness of ~10 cm or more that were caused by Strombolian activities in early periods and ballistic ejecta (a few tens cm) from the latest Vulcanian activity in November 2015. One of lava lobes in the northern area has a chilled margin that is characterized by a few-cm-thick glassy rim with many fine cracks developed perpendicular to the lava surface. From boats, we also observed clefts along the axial crest of lobes, exposing the interior of massive part of lava flows. They are thought to be products from lava inflation driven by an increase of internal pressure by successive injection of new lava into the lobes during lava emplacement as proposed by Maeno et al. (2016). We collected samples from lava lobes and fallout deposits for petrologial analyses. The analyses were carried out together with other rock samples collected by different surveys at Nishinoshima (by ERI using an unmanned helicopter in June 2016 and by Japan Coast Guard in October 2016). The 2013–2015 lava flows were andesite with <10 vol.% of phenocrysts of plagioclase, clinopyroxene, orthopyroxene, and titanomagnetie. The whole-rock composition is 59.5–59.9 wt.% in SiO_2, analyzed by an XRF at ERI. The petrological features of the 2013–2015 lava flows are similar to those of products from the past eruptions at Nishinoshima (e.g., Umino and Nakano, 2007); however, the whole-rock compositions are clearly distinguished from the 1973–1974 products and the pre-1702 products (older lava), and lies on the narrow range between these two products. Moreover, it seems that the SiO_2 (MgO) contents of lava flows slightly decreased (increased) with time, indicating more differentiated magma was erupted in early stage, although those of fallout deposits doesn’t show such specific chemical trend through the eruption. Although more geological and petrological analyses are needed to explain the origin of chemical variations in products, our findings during surveys at new Nishinoshima offer important insights into understanding the eruption process of this volcano.

Keywords: Nishinoshima, lava, lava lobe, fallout deposit

Long-term seismic monitoring around Nishinoshima, Izu-Ogasawara by using ocean bottom seismometers

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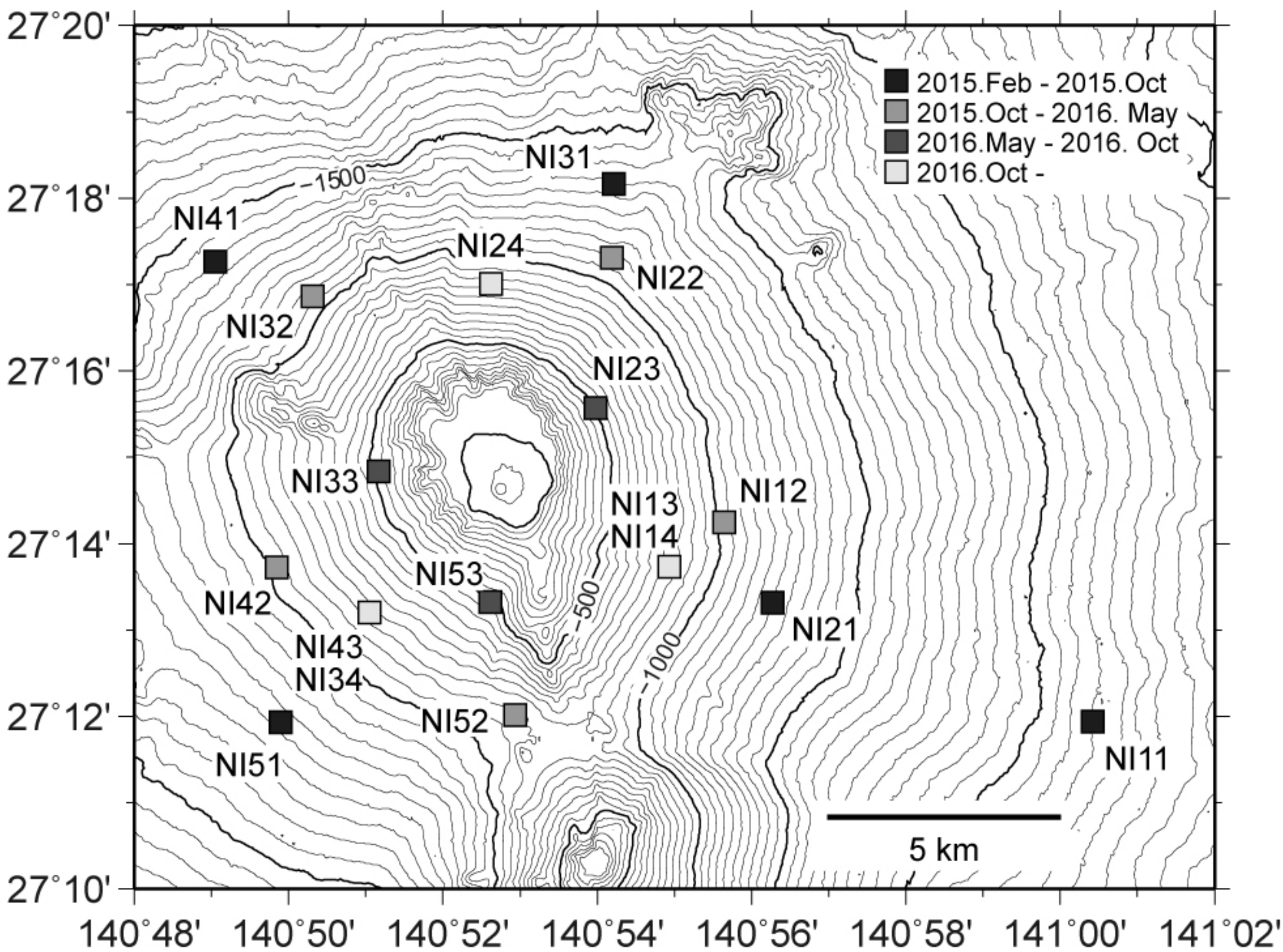
Nishinoshima in Izu-Ogasawara erupted in 1973 and island was newly created. In November 2013, eruption of Nishinoshima volcano was confirmed again and a size of the island increased. It is difficult to make continuous observation on an uninhabited island such as Nishinoshima. Therefore we started seismic observation using Long-Term Ocean Bottom Seismometers (LT-OBSs) from February 2015 when the eruption occurred continuously. Our LT-OBS equips three-component 1Hz seismometer, and has a recording period of one year. The first deployment was carried out by the R/V Kairei, JAMSTEC. We deployed 4 LT-OBSs at a distance of about 8 km from a central crater of Nishinoshima where water depths are about 1,400 m and a LT-OBS at a distance of about 13 km. In October 2015, the deployed LT-OBSs were recovered by the R/V Keifu-maru, JMA, and 5 LT-OBSs were installed to continue the observation. Five LT-OBSs were had a distance of 5 km from the crater and water depth is about 1,000 m. In May 2016, the the R/V Shoyo, JCG retrieved the 5 LT-OBSs and deployed 5 LT-OBSs at positions closer to the island. In October 2016, 5 LT-OBSs were recovered by the R/V Shinsei-maru, JAMSTEC and 3 LT-OBSs were installed again to continue the observation. We will report temporal variation of activities of Nishinoshima volcano from the records of LT-OBSs.

LT-OBSs frequently recorded characteristic events from a start of the observation. The first part of the events has high frequency of a few Hz and large amplitude waves with a period of a few seconds follows. This characteristic waves have good S/N ratio at frequencies from 4 Hz to 8 Hz. Duration of the events are less than 1 minutes (usually 20-30 s) at frequency band of 4-8 Hz. Therefore we applied the band pass filter of 4-8 Hz to all records from OBSs for analyses. For the first period, four LT-OBSs had the same distance from the crater and the waves arrived at the same time with the same amplitude. We located hypocenters of these events using the first arrival times, and epicenters were located close to the crater. In February 2015, infrasound and picture observations were performed on the R/V Kairei, and infrasound was observed during release of plume from the crater. Compared the events recorded by a LT-OBS deployed during the infrasound observation with infrasound data (1-7 Hz) and picture of the crater, the events on the LT-OBS records seem to correlate with release of plumes.

We estimated the number of the events which are related to plume release by using the STA/LTA method. The method is applied to the records of more than three LT-OBSs. First, a bandpass filter of 4-8 Hz was applied to all the records and we adopted parameters of the STA/LTA method as follows, STA window: 2 s, LTA window: 40 s, STA/LTA ratio: 1.5, duration of trigger: 3 s, time for re-trigger: 4 s. The events are recognized by more than three triggers at the same time, and continuous trigger is interpreted as one event. We detected 363,367 events from 2015 February 28 10:00 to 2015 October 3 13:00 (the first observation period). In the second observation period (from 2015 October 4 01:00 to 2016 May 5 08:00), 27,544 events were picked up. For the second period, we changed the parameter of STA/LTA ratio to 2.0 due to a change of configuration of the LT-OBS network. From the start of the OBS observation (2015 February) to June, the number of detected events is constant of approximately 1,800 per day. From middle of July 2015, the detected number rapidly decreased, and duration time of the events became longer. In the end of October 2015, the number was reduced to less than 300 per day.

Although the number temporarily increased at the beginning of November, the number of the detected events reached less than 100 per day after the end of November. It is estimated that the surface activity of Nishinoshima volcano declined from the end of July 2015, and there was little activity from the middle of November 2015 to at least May 2016.

Keywords: Nishinoshima volcano, Long-term ocean bottom seismometer, Temporal variation of activity of Nishinoshima volcano



First operation of the remote-island volcano monitoring system around Nishinoshima

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We develop a remote island volcano monitoring system by using the Wave Glider (WG), which monitor the volcanic activity of remote islands while autonomously navigating around the island far from the land, and transmit the information to the land station by satellite communication. During the KS-16-16 cruise of R/V Shinsei-maru in October, 2016, we deployed the newly developed system into the Nishinoshima sea area, and the short-term operation was performed. The monitoring system is equipped with 1) the 4 time-lapse cameras for taking pictures of volcanoes, 2) the 2 microphones for infrasound observation, 3) the hydrophone installed at 6 m below sea surface for earthquake observation, and 4) the wave meter utilizing GPS Doppler velocity measurement for detecting tsunami generation by the land slides of the volcanic body. Sound wave signals by the microphones and hydrophone, and the wave meter records are transmitted by the satellite communications to the land station. For the navigation and control of the WG, other satellite system is employed, and the navigation data set (location, speed, current speed and direction), and the weather data set (temperature, pressure, wind speed and direction) are transmitted independently to the land.
The system is launched about 1km west to the Nishinoshima at 0935 on October 20, 2016. After the launch, the system start navigation autonomously along the track of circling the island with a radius of about 5 km. After one circle of the track, the system was recovered on board at the north-west to the island at 1345 on October 21, 2016.The average amplitude of the observed sea waves was about 50 cm, and the period was around 10 sec. The water speed of WG was in the range of 1.2 - 0.9 knots. On the other hand, the ground speed observed by the GPS Doppler measurement had the mean speed of 0.5 knots, and it took more than 30 hours for travelling the distance of 30 km along the circular track.
The wave meter measures and records the heave and the three components of speed with 10 Hz sampling rate. In normal mode, data communications via satellite to the land station transmit 1 Hz sampling data sets (about 600 byte) in every minute. In emergency mode, 10 Hz sampling data sets (about 4900 bytes) are transmitted in every minute. In the present experiment, the normal mode transmission of the date sets were performed without an error, and the switch between two modes was successful. Heave and speed measurements of the wave meter are performed with the precisions cited in the specification (5 cm in heave, and 0.05 m/s in speed). The frequency spectrum of the heave seems closely resemble that of the wind generated waves in typical coastal area with a central frequency of 0.1 Hz.
Sound waves observed by the microphones and hydrophone were recorded by the data logger at sampling speed of 200Hz. Examination of the data sets indicates that the waveform of the microphones are highly correlated with that of the waves, suggesting that the microphone records the pressure change by the up-down movement of the float of WG. Since the Nishinoshima volcano did not erupt at that time, the high frequency signals more than 2Hz corresponding to the infrasound waves were not observed in the microphones. On the other hand, many line spectra are seen in the higher frequency side (>10 Hz) of the hydrophone spectram. During KR-15-17 cruise of R/V Kairei in Feburuary 2015, we made hydrophone measurement by lowering the hydrophone from the ship to the water depth of 10m, while the Nishinoshima volcano was highly active and continuous eruptions occur. The spectrum of the hydrophone records show many line spectra higher than 10Hz, which corresponds to BH-type earthquakes. Considering the observation in 2015, it seems that the activity of the deep part of the

Nishinoshima volcano does exist even now.

Keywords: Nishinoshima, Remote island, Volcanic activity monitoring

The October 7-8, 2016 eruptions of Nakadake crater, Aso Volcano, Japan and their deposits

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The Nakadake first crater of Aso Volcano (SW Japan) erupted at 21:52 on October 7, 2016, and the first eruption was followed by an explosive activity at 01:46 on October 8. The October 8 explosive eruption produced ash plumes rising to altitude of 11000 m asl that drifted E-ESE. The ash-fall deposit was dispersed over an area extending 350 km northeast of the volcano. We performed fieldwork for observing and sampling of the related deposits in the proximal and distal areas immediately after the eruption.
The October 7-8 eruptions emplaced a large amount of poorly-sorted deposits containing abundant block-size clasts around the Nakadake first crater. Although the total thickness of deposits associated with the October 7-8 eruptions at the southwestern crater rim was about 1 m, the maximum thickness was likely to reach 1.5-2 m because some shelters (2-2.5 m high) were almost buried by the deposits. A large number of ballistic clasts of a few ten centimeter across was scattered around the crater, and the largest clast with a size of 3×2.2×1.5 m existed at the southwestern crater rim. Since several lobate deposits of 0.5-1 m high and a few meter wide occurred along gullies in the proximal area, most of proximal deposits were interpreted to be derived from pyroclastic density currents (PDCs). Based on a helicopter inspection immediately after the eruption, the mass of the PDC deposits was roughly estimated at 4.5×10^5 tons.
The October 8 ash-fall deposit was clearly distributed about 70 km to the northeast of the source crater. Lapilli-size clasts were dispersed to areas up to about 30 km east-northeast of the crater. The dispersal axis of the maximum size of clasts was slightly more easterly than that of thickness. The mass of the ash-fall deposit (including lapilli-size clasts) was calculated at about 1.8×10^5 tons. Adding the mass of the PDC deposits, the total eruptive mass of the October 7-8, 2016 event was $6\text{-}6.5\times10^5$ tons.
The polarizing microscope observations revealed that a sample of the October 8 ash-fall deposit consisted of glass shards (20 %), crystal (20 %) and lithic (60 %) grains. Most glass shards were unaltered poorly crystallized pale brown glasses and highly-crystallized black glasses, which probably represented juvenile magma. Results of EPMA analysis indicate that chemical composition of glass shards included in the October 8 ash-fall deposit was similar to those of glasses in the 1979, 1989-1990 and November 2014-September 2015 ash.
The October 7-8, 2016 eruptions of Nakadake first crater were characterized by explosive phenomena including ballistic projectiles and pyroclastic density currents, and were similar in deposit volume to eruptions on September 6, 1979 and April 20, 1990.

Keywords: Aso Volcano, Nakadake crater, phreatomagmatic eruption, ballistic clast, pyroclastic density current

2015-16 years activity of Niigata-Yakeyama volcano; ash emission eruptions and syneruptive-spouted type lahar generated in 2016 year eruption.

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Niigata-Yakeyama Volcano, Niigata prefecture in central-Japan, consists of lava dome and pyroclastic flow and is young active volcano. Recently, in this volcano, phreatic-eruptions occurred in 1949 and 1974; small-scale eruptions (ash emissions) occurred in 1983-84, 1987, 1989, 1997-1998 and 2016. We report of the sequence of 2015-16 years activity of Niigata-Yakeyama Volcano, based on the analysis of tephra and observation from the ground and aerial. From the end of August 2015 to the fall of 2016, the fumarolic activity of Niigata -Yakeyama Volcano was active. In 2016, Niigata-Yakeyama Volcano emitted volcanic ash 8 times (6 times before April 15, once in May and July) and syneruptive-spouted type lahar 6 times (May 1-8 and 20, June 3-4 and 26, July 2 and 19). Along with these ash emissions, release of ejected rock fragments and high temperature matters has not been observed. The emitted volcanic ash was found to be composed of altered volcanic fragments, flesh plagioclases, pyroxenes and roundness volcanic rocks fragment. However, the absence of juvenile material in the eruptive products indicates that the eruption was phreatic. The estimated total discharged mass was less than 10^6kg. From these characteristics, it is estimated that the eruptions of 2016 is phreatic eruptions that occurred when the surrounding fine grains were blown off by activation of fumaroles. However, the eruption of warm or muddy water from the volcanic body (syneruptive-spouted type lahar) is a characteristic activity of 2016 eruption.

Keywords: active volcano, Niigata Prefecture , eruption, tephra, volcanic ash, syneruptive-spouted type lahar

Fumarole activity at the southwest rim of Ioyama crater in the Ebinokogen

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A new fumarole that appeared on the southwest rim of the Ioyama crater in the Ebinokogen volcanic area on 14 December 2015 spread rapidly in January–February 2016. The occurrence of frequent volcanic earthquakes in a single day, on 28 February 2016, led the Japan Meteorological Agency (JMA) to issue a level-2 volcanic alert (JMA website[1]). Although the volcanic alert level was downgraded to level 1 in March, a gradual spread of the fumarole area was observed in April and August 2016. The present study measured the high-temperature area by employing easy triangulation using two tape measures; however, this method was difficult to apply to the expanding area in late August. Therefore, air photographic survey by drone was used in high-temperature areas.
Prior to the drone observation, we set markers showing 50°C on 20, 22, 25, and 27 November 2016. Just before the day of observation on 9 December, the 50°C points were modified. Aerial footage was recorded by the Phantom 3 drone on 10 and 11 December which was then converted to orthophotographic images. Markers with diameters of 18 cm were more clearly observed about tens of meters height above ground level and were plotted on the orthophotographic images, and the areas of 50°C were then measured. The high-temperature area was 3500 m^2 on 10 December, which indicates an expansion of the 2200 m^2 high-temperature area measured on 20 August.
Very high concentrations of H_2S volcanic gas were observed in the middle of October (Miyazaki prefecture website[2]). White turbidity in the river caused by sulphur from Ioyama was found on 29 October by a member of the Kirishima Nature guide club. It was assumed that expansion of the high-temperature area was occurring at that time. On 12 December 12, frequent volcanic earthquakes occurred (JMA website[1]). The expansion of the high-temperature area from December 2015 to February 2016 and from October 2016 to the present indicates the occurrence of strong underground volcanic activity.

1 http://www.data.jma.go.jp/svd/vois/data/tokyo/volcano.html
2 http://www.pref.miyazaki.lg.jp/kiki-kikikanri/kurashi/bosai/iouyamagasu20160226.html
Observation members of Kirisima nature guide club: Toshio Furuzuno, Kentaro Haraguchi, Takeji, Nagatomo, Takamichi Higashi, Hideaki Yoshinaga, Midori Baba, Masashi Takada, Yukikazu Matsumura.

Keywords: Kirishima volcanoes, Ioyama, Fumarole

Time variation in the volcanic gas at Hakone volcano with the interpretation

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Introduction
At Mt Hakone, the swarm of volcanic earthquakes happed in June to Oct 2001 with the pressure increase of steam discharged from boreholes drilled in Owakukdani geothermal area. A similar phenomenon happened in the end of April 2015. During the occurrence of earthquake swarm in 2015, a small steam eruption happed in Owakudani geothermal area. We should expect another earthquake swarm and eruption at Mt Hakone in future. In general, the chemical composition and isotope ratios of volcanic gas change along the progress of volcanic activity. The prediction of earthquake swarm based on the volcanic gas contributes the mitigation of volcanic hazard at Mt Hakone. In this study, we report the chemical composition and isotope ratios of fumarolic gas sampled at Mt. Hakone since May 2013, and try to interpret the time variation.

Fumarolic gas
We have sampled two fumarolic gas at fixed location with the frequency of once per month. One point of sampling is located within Owakudani geothermal area. Another point of sampling is located in Kamiyuba geothermal area, 500m far from Owakudani gothermal area in north direction.

Result and discussion
A significant increase in CO2/H2O ratio happed in May 2015, at the both fumarolic gas, which synchronized with the start of volcanic earthquake swarm. The increase could be brought by the development of sealing zone surrounding a degassing magma. The sealing of degassing magma increases the pressure of magma and also increases the CO2/H2O ratio of gas equilibrated with magma. A magmatic fluid with high CO2/H2O ratio would be injected to the shallow hydrothermal system after the break of developed sealing zone. The injection produced the earthquake swarm, the pressure increase in steam from bore holes, and the increase in CO2/H2O ratio of fumarolic gas.
Before the earthquake swarm in April 2015, a significant increase in N2/He ratio was observed. The increase started in Feb 2015, being kept until the start of earthquake swarm. The change can be also explained by the magma sealing model. Before the break of sealing zone, the supply of magmatic fluid to the shallow hydrothermal system had been suppressed. The fluid pressure in the hydrothermal system was lowered by the suppression, which induced the invasion of atmospheric air from surface. The contaminated air was involved in the fumarolic gas, which caused the increase in N2/He ratio.
The fumarolic gas from Mt Hakone contains H2 gas and H2O vapor. An apparent equilibrium temperature (AET) can be calculated by use of D/H of H2O and H2. The AET was stable with average around 100C before Aug 2014 for both fumarolic gases, and dropped to 70C after Sep 2014. The drop continues about 2 months. During the occurrence of volcanic earthquake in 2015, AET increase to 130C in average. After the earthquake, AET was stabilized to 110C in average. The drop of AET may be a precursor for the earthquake swarm in 2015.

Keywords: Volcanic gas, Mt Hakone, Eruption

Thermal activities around Shrirane pyroclastic cone, Kusatsu-Shirane volcano

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Phreatic eruptions have repeatedly occurred at Shirane pyroclastic cone, Kusatsu-Shirane volcano, over the last 130 years. Shirane pyroclastic cone exhibits thermal features such as hot crater lakes and steaming grounds. The most active hot crater lake, Yugama, contains extremely low pH water resulting from subaqueous fumarolic activities. On the northern slope of Shirane pyroclastic cone, vigorous steaming grounds emit volcanic gas which is mainly composed by H_2O, CO_2 and H_2S with a temperature of around 100 degree Celsius. MT surveys have revealed that a low resistive layer exists beneath Shirane pyroclastic cone. The layer may act as an impermeable layer enabling to store volcanic fluids supplied from depth. According to precise geophysical observations, hypocenters of micro earthquakes are located around undersurface of the impermeable layer. Sources of Long-period events, ground deformations and magnetizations are determined around the impermeable layer, meaning hydrothermal reservoir exists under the impermeable layer.

Thermal manifestations of Shirane pyroclastic cone are likely caused by fluid leakages from the reservoir; I believe monitoring of thermal activities are useful to evaluate activities of the hydrothermal reservoir. To estimate heat flux from vigorous steaming grounds, precise measurements of spacial distributions of ground surface temperatures are necessary. Using an infrared thermography, aerial infrared surveys have been repeatedly carried out since 2012. Most of these observation were done in the nighttime because even slight anomalies in ground surface temperature can be detected.

Intense earthquake swarms have occurred at shallow depth of the Shirane pyroclastic cone since March 2014, accompanied by ground deformations, changes in geomagnetic field and chemical concentrations of volcanic gas. A location of the pressure source is determined by network of our tilt meters at 550 m depth from Yugama crater lake, corresponding to the location of hydrothermal reservoir. We consider that increases in heat-discharge rates observed in 2015 and 2016 mean fluid leakages from the reservoir.

On the southeast slope of Shirane pyroclastic cone, no anomalies of ground surface temperatures were detected by the aerial infrared surveys while phreatic explosions occurred between 1927 and 1942 in this region. Fumaroles with a temperature of 148 degree Celsius emitted volcanic gas containing SO_2 and HCl in the early 1960s in the region. We believe that such intensive explosions developed permeable zone in the cap rock layer beneath the Shirane pyroclastic cone, as a result, high temperature volcanic gas emitted from here exclusively.

I find a stream which hot water springs out from the streambed. We collect water sample and measure flow rate systematically in order to estimate temperature, enthalpy, pH, concentrations of anions and stable isotope rates of hydrogen, oxygen and sulfur. Furthermore, Volcanic Fluid Research Center (VFRC), Tokyo Institute of Technology, has dug a monitoring well at 700 m east from the center of Yugama crater lake in 2016. At the depth of 50 m, VFRC finds a hot water vein with a temperature of 31 degree Celsius. Inserting a slender bottle to the well VFRC can easily collect water sample from 50 m depth. In addition to the thermometer installed in 2016, VFRC plans to install sensors of water level, pH and electrical conductivity in the well. These physical and chemical features of water in the southeast slope of Shirane

pyroclastic cone enable us to discuss signs of magmatic high temperature volcanic gas leakage from the hydrothermal reservoir.

Keywords: Kusatsu-Shirane Volcano, Hydrothermal system, Fumaroles, Monitoring well, Infrared thermography

Magmatic hydrothermal system inferred from the resistivity structure of Kusatsu-Shirane Volcano

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Kusatsu-Shirane volcano consists of two main pyroclastic cones. One is Mt. Shirane located in the northern part of summit area, which has three active crater lakes. Various geochemical and geophysical researches have been conducted and several models of the subsurface structure and the hydrothermal system have been proposed. The other is Mt. Motoshirane located about 2 km south of Mt. Shirane. In this area, no volcanic activity is observed today, and therefore studies targeted for this cone have not been conducted other than several geological studies. Two major hot springs of the volcano, Kusatsu and Bandaiko hot springs which are characterized by high-temperature and high-discharge-rate, occur in the east flank of Mt. Motoshirane. The recent geological study revealed that the last magmatic eruption had occurred from Mt. Motoshirane about 1500 years ago.

We conducted a magnetotelluric (MT) study on the subsurface structure of Mt. Motoshirane in this study. The MT method is a kind of electromagnetic method to infer the subsurface structure and sensitive to conductive materials such as melt and hydrothermal fluids. The objective of this study is to clarify the whole image of magma-hydrothermal system of Kusatsu-Shirane volcano. The final three-dimensional (3-D) resistivity model revealed the presence of a conductor (henceforth we call it C2) beneath the summit area extending from Mt. Shirane to Mt. Motoshirane. Since the horizontal extent of this conductor covered two clusters of hypocenter distribution which are located within each pyroclastic cone, the conductor was interpreted as a hydrothermal fluid reservoir providing fluids to the shallow terrain and causing volcanic earthquakes. From the result of the 3-D resistivity structure indicating no conductor which is considered to preserve such volcanic fluids in the region between the hot springs of the east flank and C2, we consider that the conductor C2 is a source of the heat and fluid of Bandaiko and Kusatsu hot springs, and propose the following model of a hydrothermal system of the volcano.

The region beneath the C2, a heat source is located and provides the heat and fluids to C2. The heated fluids in C2 ascend to the summit area, causing volcanic earthquakes. A part of the heated fluids ascends to the east flank of Mt. Motoshirane, through fractures of the Kusatsu fault, and forms a hydrothermally altered zone and fumarolic zones such as the Sessho fumarolic area. Mixture of ground water and the fluids from C2 flows down to the east flank of the volcano and is discharged as Bandaiko and Kusatsu hot springs.

In a deep part of the volcano, no conspicuous feature indicating the existence of magma was found in the final resistivity model. However, it does not necessarily mean that there is no magma chamber beneath the region. Additional observations and/or simulations are required in order to constrain the location of magma, which should be carried out in the future.

Keywords: Kusatsu-Shirane volcano, Mt. Motoshirane, resistivity structure, hydrothermal system, magma reservoir

Three-dimensional resistivity structure around the lava dome of Chausu-dake volcano inferred from the AMT measurements

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Chausu-dake volcano is located in the northern part of Tochigi prefecture, and started volcanic activity about 16000 years ago. Six large-scale eruptive activities including the magmatic eruptions and many phreatic explosions were reported. The last large-scale activity occurred during 1408-1410 and formed a present lava dome in the summit area. After that, several phreatic explosions occurred repeatedly and formed two craters on the northwestern side and western side of the lava dome on July 1st, 1881. Recently, phreatic explosions occurred in these craters in 1953, 1960, and 1963, and fumarolic activities are observed there today.

According to the observation by the Japan Meteorological Agency (2015), the fumarolic temperature decreased gradually after the phreatic eruption of 1963 and is kept at about 100℃ recently. Volcanic earthquakes within the edifice are hardly observed and the plume height is low. It seems that volcanic activity is quiet. It is important to know the subsurface structure of the volcano which is in a decreasing volcanic activity. This is because the inner structure of a quiet volcano provides the basic information to know the present state of volcanoes in the increasing activity. Therefore, we investigated the resistivity structure around the lava dome of Chausu-dake volcano using audio-frequency magnetotelluric (AMT) method.

An AMT measurement was already conducted around Chausu-dake volcano by Aizawa et al. (2009) and two-dimensional resistivity structure was inferred. The result shows that the volcano constitutes a thin resistive layer underlying a thick conductive layer. The conductive layer was considered to be composed of the upper layer which is rich in conductive clay minerals and therefore has low permeability and the lower layer containing hydrothermal fluids. The altered layer was considered to act as both the base for meteoric groundwater flows and the cap for hydrothermal fluids. However, the model of Aizawa et al. (2009) was obtained from a two-dimensional inversion using only the TM-mode data, although the data showed three-dimensional (3-D) features. In addition, the AMT data was measured along a mountain trail south of the lava dome, so a detailed subsurface structure of the lava dome is still unknown..

In this study, we carried out an AMT survey in the whole area of the lava dome in 2016 to clarify more detailed structure beneath the lava dome of Chausu-dake volcano. In the presentation, we are going to report a three dimensional resistivity structure model inferred from the AMT data observed by this study and of Aizawa et al. (2009), in which the topography is incorporated.

Keywords: Nasu volcano group, Chausu-dake volcano, AMT, lava dome, resistivity structure

Geoelectromagnetic investigations of Yake-dake volcano - wideband magnetotelluric measurements and magnetic survey -

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In order to delineate subsurface structures as basic information for monitoring Yake-dake volcano, we carried out wideband magnetotelluric (MT) measurements. For clarifying electrical properties, we totally obtained electromagnetic data at 11 sites along a north-south profile and estimated MT responses by using the remote reference technique. Obtained preliminary result of a two-dimensional inversion reveals a cap-like conductor just beneath the latest phreatic eruption. Additionally, we performed ground magnetic survey along a north-south profile crossing the summit of Yake-dake volcano. To simulate obtained magnetic anomaly, a zone of low magnetization is required at the same location as the cap-like conductor.

Keywords: Yake-dake volcano, magnetotellurics, ground magnetic survey

Vertical ground deformation after the August 2015 dike intrusion event at Sakurajima volcano measured by leveling survey

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We conducted the precise leveling survey in Sakurajima volcano in November 2016. The main purpose of the survey is to reveal the vertical ground deformation after the dike intrusion event occurred on August 15, 2015. The leveling routes measured in this survey are about 56 km long in total, including Sakurajima coast route, Sakurajima western flank route and Sakurajima northern flank route. These leveling routes were measured during the period from November 1 to 24. Mean square errors of the conducted survey were achieved with a good accuracy as the range from ±0.14 to ±0.26 mm/km.
From the measured data, we calculate the relative height of each bench mark referred to the reference bench mark BM.S.17 which is located at the western coast of Sakurajima. The calculated relative heights of the bench marks are then compared with those of the previous survey conducted in August-September 2015 (Yamamoto et al., 2016), resulting in the relative vertical displacements of the bench marks during the period from August-September 2015 to November 2016.
The resultant displacements indicate the remarkable ground uplift at bench marks around the northern part of Sakurajima. The amount of the maximum uplift is as much as about 20.5 mm referred to BM.S.17. On the other hand, the ground subsidence is detected around Arimura (southern part of Sakurajima). From the preliminary analysis based on Mogi’s model, the inflation and deflation sources are located beneath the northern part of Sakurajima and beneath the east of Showa crater, respectively. The inflation source represents the magma accumulation around the location, while the deflation source is supposed to reflect the pressure decrease related to the previously intruded dike.

Keywords: Sakurajima volcano, precise leveling survey, vertical ground deformation

The viscoelastic responsive interpretation by ground deformation observations of magma intrusion event into Sakurajima volcano on August, 2015 that contained pre- and after- activities.

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Introduction

Failed eruption, Magma intrusion event into Sakurajima volcano, occurred in August, 2015. From about 7:05 of 15th, VT earthquake was observed, and ground deformation was observed by tiltmeter and extensometer from about 8:00. Following, VT-seismicity became active, and the ground deformation rates increased from 10:27. Low frequency earthquake, large amplitude, was observed on 11:32 and 11:43. Subsequent VT-seismicity and ground deformation gradually became low-active. Ground deformation, like a after slip deformation, continued until about 17th(named intrusion process). By multi parameter ground deformation obsevation (tiltmeter,extensometer,GNSS,InSAR), the intrusion process is interpreted as WNW-ESE tensile crack, tips at 1km b.s.l, and volume change is about $10^6 m^3$ (e.g. Hotta et al., 2016 and Morishita et al., 2016). In followed period (named relaxation process), deformation polarity turned over. At the observation point near intrusion source (e.g. arimura), the deformation was exponentially, as viscoelastic stress relaxation process. On the other hand, at remote point, it seems to be also affected by other factor. In this study, We investigated the spacial-temporal pattern of intrusion process and relaxation process in detail.

Data and Methods

We analyzed tilt and strain data observed at the sites on Sakurajima, operated by SVO and JMA. We divided a intrusion process into 4 stages and defined 5 stage (4stage and relaxation process). (A: 08:00-10:27 B: 10:27-11:15 C: 11:15-11:45 D: 11:45, 15th-18:00, 17th E: 18:00, 17th-)

For each stage, We estimated source by dislocation model (Okada, 1992). Observation data at each sites are coordinate conversion to the directions of calculation value by best fit model. We analyzed the normalized conversion data, temporal response series.

Results

For the tilt data at Arimura, We assumed delay time. Delay time is response factor, assumed Kelvin-Voight medium, when it give step function at the beginning of each stage. The delay time is approximately 50 minutes in stage A - C, but is approximately 360 minutes in stage D. In stage E, relaxation time is approximately 90days (1.3×10^5min) and approximately 40% returned.

It was accepted that delay time is correlation with the distance from the source by relative impulse response (other site to Arimura). In addition, the response at sites in the tensile direction are more rapid than that in the strike direction. At the tensile direction, relative delay time increased from 8:00 to 11:45 on 15th, in following Stage D, it gradually decrease. For Stage E, relative relaxation time have the same correlation. This means inverse correlation with the ratio of deformation in StageE to in StageA-D.

Discussions in meeting

The decrease delay in stage D is interpret as stress relaxation of local stress concentration, diffusion from the source neighborhood to the around. Thus, it will discuss in the details by comparison with VT-seismic activity.

The deformation at Arimura in Stage E is interpreted as delay response by decline of the magma or strain relaxation by stress (pressure) relaxation of intrusion magma. But, These at other sites don't do an exponential change until about October, 2015. We will estimate stress field to make a comparison

between the overlaps and after-VT seismicity, became active a little at slightly remote resion from source in September to October, 2015.
The density of fluid in the crack just after the intrusion is estimated at 0.98±0.37g/cm^3 (Kazama et al., 2016). It seems to be very foaming advanced magma. Therefore, we will consider whether it can interpret above characters by upward or lateral gas diffusion.

Keywords: Sakurajima volcano, magma intrusion, viscoelastic response

Absolute gravity signals at the Sakurajima volcano since 2009 through 2016

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In this paper, we present gravity signals based on continuous absolute gravity measurements since 2009 through 2016. During this period, several hundreds to a thousand eruptions/explosions were observed every year until July 2016. In particular, significant seismicity and crustal deformations were observed on Aug. 15, 2015, followed by unusual quiescence since August 2015.
Gravity signal after eliminating groundwater disturbance showed remarkable features during several major volcanic events, such as (1) vulcanian eruption from the Minamidake A crater on July 24, 2012, (2) formation of lava dome at the Showa crater in January to February 2015, and the dyke intrusion events on Aug. 15, 2015.
Correlation between the two time series of gravity change D$g(t)$ and tilt/strain changes D$e(t)$ is essential to discuss the volcanic process of these events. For example, time lag between D$g(t)$ and D$e(t)$ is negligibly small during the dyke intrusion (Aug., 2015) while D$g(t)$ during the other period shows significant time lag (~1 day) to D$e(t)$. In addition the amplitude ratio |Dg/De| during the dyke intrusion event assumed a value expected from the dislocation theory, while it is 100 times larger than the expectation during the other events. These characteristics are well explained in terms of the conduit status (open/closed). When the conduit is closed as in the case of the dyke intrusion event, both strain/tilt and gravity are principally governed by instantaneous elastic deformation, which implies absence of time lag. On the other hand, when the conduit is open as in the explosion period other than the dyke intrusion event, inflation/deflation of magma chamber does not cause effective elastic deformation, which means larger |$g(t)$ / $e(t)$| compared to the case of closed conduit and significant time lag of $g(t)$ to $e(t)$ because magma migration in a conduit requires certain amount of time.

Keywords: Gravity, Sakurajima volcano, conduit

Temporal change in transfer function using ACROSS associated with magma intrusive event in 2015 in Sakurajima volcano, Japan

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We detected a temporal change in propagation property of seismic wave associated with a magma intrusive event on 15 August 2015 of Sakurajima volcano, Japan. The propagation property, which is called transfer function (Green's function), has been monitored continuously since 12 September 2012 using an accurately-controlled seismic source (ACROSS) and seismic stations in Sakurajima volcano island. The change in the transfer function was calculated with 2-hour resolution. Large change is detected in the initial stage of the intrusive event, when the rate of crustal deformation was maximum. The amount of change associated with the intrusive event shows a spatial variation, depending on the location of the seismic stations. We calculated cross covariance between the transfer functions before and after the event. The cross covariances for the stations near the craters of 1914 Taisho eruption show larger reduction than those in the peripheral area even for the stations of comparable distance from the ACROSS source. The stations that show large reduction of cross covariance also show phase advance toward coda part, meaning velocity increase of the media. The amount of velocity increase is estimated to be about 1%. This indicates that the velocity increase is caused by the stress increase due to the magma intrusion. The stations in the peripheral area, which shows little reduction of cross covariance, also show little velocity change even in the same direction from the intrusion source. This may result from spatial variation of stress sensitivity of the medium in the volcanic body. The material near the Taisho craters of Sakurajima volcano is more sensitive to stress probably due to less compaction of eruption material.

Keywords: Temporal variation of seismic velocity, Scattering of Seismic wave, Stress Sensitivity

The final round of the repeating seismic experiment in Sakurajima Volcano, Japan. The experiment 2016.

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1. Akita University, 2. Kyoto University, 3. Hokkaido University, 4. Tohoku University, 5. Tokyo Institute of Technology, 6. University of Tokyo, 7. Nagoya University, 8. Kyushu University, 9. Kagoshima University, 10. Japan Meteorological Agency

The final round of the repeating seismic reflection experiments in Sakurajima Volcano and their summary are presented. The experiment series aims detection of structural evolution associated with underground magma movement in Sakurajima Volcano, which is a project included in the national project "the Earthquake and Volcano Hazards Observation and Research Program". The experiment is the first seismic experiment after the 2015 intrusion event, which was carried out after two years of the previous round. Seismic experiments have been performed every Decembers since 2009 with the identical geometry in the northern and eastern part of Sakurajima. Two major lines are routinely included and comprise 14 shot points and 225 stations in these experiments. Another line were also deployed in 2016 in the east foot of Minamidake with additional 20 stations for the purpose of detection of change in seismic response around the 2015 intrusion area. Uniform instruments, LS-8200SD by Hakusan Industry and Vertical motion 4.5Hz sensor, and 20kg size chemical explosions are used. The detonations for the final round experiment was done on 8th December 2016. 98.4% of all stations were completed schedule and seismograms up to 13 Gbytes were obtained through the experiment.
Tsutsui et al. (2016, JVGR) compiled seismic sections through six years, and presented that there is a reflector which changes associating with volcanic activity at depth of 5.8km below sea level. The reflector, Alpha, located beneath northeast Sakurajima, in the north of the known pressure source presented by Iguchi (2013, BVSJ). Tsutsui et al. (2016, JVGR) presented that the reflectivity of Alpha built up as the intrusion event in 2009 - 2010, and was fading after. The reflector did not respond the second intrusion from 2011 through 2012.
Further considerations on data in cross-line observations for seven rounds revealed three more clear later phases. Those were presented by Tsutsui et al. (2016, JpGU meeting).
1) A clear PS conversion from 5.8 km depth appears in 2012,
2) A clear PP reflection from 4.7 km depth appears in 2009,
3) A clear PP overcritical reflection from 2.4 km depth appears in 2012.
All of these are located in two kilometer south of reflector Alpha and their locations are coincident with the known pressure source by Iguchi et al. (2013).
Data of 2016's experiment suggest that intensity of several reflectors has changed after the previous round as followings ;
1) The reflector at 5.8 km depth has faded.
2) No PS conversion from the reflector at 5.8 km is detected.
3) Enhanced reflection from 4.7 km depth.

4) Enhanced reflection from 2.4 km depth.
The facts suggest there was structural evolution possibly associated with the 2015 intrusion beneath Sakurajima Volcano.

This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under its Earthquake and Volcano Hazards Observation and Research Program, also supported by Japan meteorological Agency and DPRI, Kyoto University. The instruments for routine experiment are provided by Earthquake Research Institute, University of Tokyo.

Keywords: Sakurajima Volcano, Reflection seismology, Magma

Shallow crustal velocity structures obtained from ambient seismic noise study in the Aso caldera

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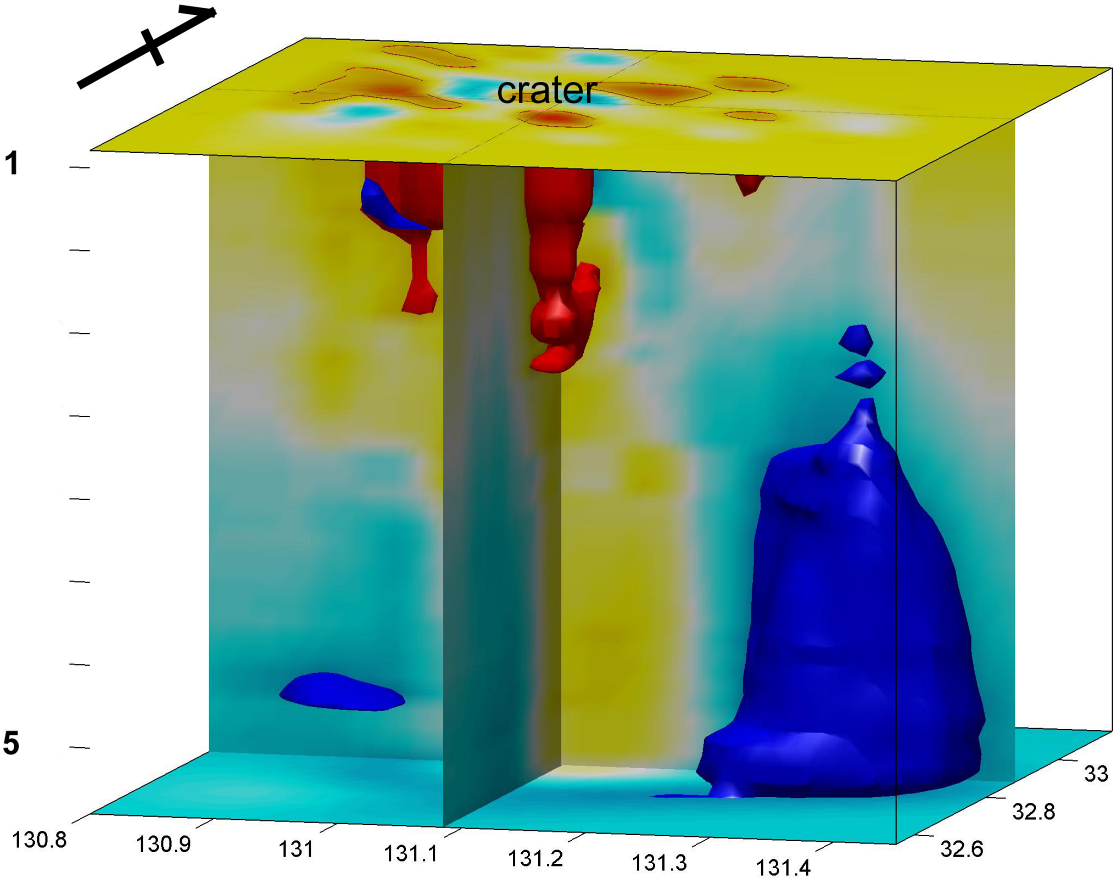
The Aso volcano is situated approximately in the central of Kyushu and is one of the most active volcanoes in Japan. There were four gigantic eruptions occurred and present caldera was formed about 89 ka known as Aso-4 eruption, with around 18 km in E-W and 25 km in N-S direction. Recently, the major volcanic activities focus on the post-caldera central cones, especially the first crater of the Mt. Nakadake. The conceptual volcanism and magma plumbing system of the Aso volcano were investigated with various geophysical and geodesic observations. The magma chamber is approximately spherical, located 3–4 km southwest of Mt. Nakadake (around Mt. Eboshidake) at depths of 6-10 km. Fumaroles and surface geothermal activities also expose in the southwest flanks of Mt. Eboshidake.
Analyzing ambient seismic noise signals has been routinely used to investigate the subsurface shear-wave velocity structure around the world in the past decade. Some studies also demonstrated it is possible to monitor the magma and hydrothermal fluid movement, or seismic velocity variations beneath active volcanos from the temporary changes of cross-correlation functions (CCFs). The seismic activities of Aso volcano have been monitored with around 20 broadband and short-period seismometers operated by Aso Volcanological Laboratory (AVL). The seismic dataset also included five permanent broadband stations operated by Japan Meteorological Agency (JMA) or National Research Institute for Earth Science and Disaster (NIED), which are located inside and surrounding the Aso caldera.
The interstation distances are much shorter (1-2 km) near craters on the Mt. Nakadake comparing with station-pairs surround the Aso caldera (10-20 km). Seismic data is daily vertical component between November 2009 and September 2013, i.e., before recent eruptions started on 25 November, 2014. Raw data were firstly transferred from WIN to SAC format and downsampled to 20 Hz. After primarily checking data quality, the daily CCFs were obtained in the 1-10 s period band for broadband station-pairs and 0.2-5 s for short-period station-pairs. Daily CCFs were stacked monthly, and then monthly CCFs were stacked again to further obtain Rayleigh wave phase velocity dispersion curves. The 2D and 3D phase velocity maps were mainly constructed in the 1-5 s period band and to determine the predominant velocity distributions.
Generally speaking, Rayleigh waves are sensitive at depths approximating one-third of wavelengths and vary with periods. Therefore, the sensitive depths of S-wave velocity structures ranged from approximately 0.7-5 km in this research. At most of periods, low velocities are dominant underneath the post-caldera central cones and the western portions of the Aso caldera, which might be corresponding to magma conduits and geothermal activities. High velocities are observed in the east of Mt. Nakadake and also the regions surround the Aso caldera, which might be related with much earlier volcanic activities that stopped recently.
The obtained velocity structures in this study can be as a reference, which were obtained with seismic data before latest eruptions. More recent seismic data should be easier to observe temporary variations of daily CCFs, which might be related to the movement of magma or hydrothermal fluid that cause temporary velocity structural variations in the shallow crust. More dense seismic stations might be required to image more detail 3D velocity structures and temporary variations.

Keywords: ambient seismic noise tomography, Aso caldera, shallow crust


crater
1
5
130.8
130.9
131
131.1
131.2
131.3
131.4
32.6
32.8
33

Ground deformation source model at Kuchinoerabu-jima volcano during 1995–2014 as revealed by repeated GPS observation

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We analyzed repeated GPS observation data in Kuchinoerabu-jima during August 1995–April 2014. Most stations located around the Shin-dake crater showed crater-centered radial horizontal displacements. There was a tendency that observed horizontal displacements at western rim of the Shin-dake crater were larger (16.6–20.6 cm) compared to those at eastern rim (7.8–11.6 cm). In addition, station KUC14 which locates approximately 500 m south of the Shin-dake crater showed westward horizontal displacement rather than crater-centered radial (southward) one. On the other hand, small displacements (less than 2 cm) were detected at the stations located at the foot of Kuchinoerabu-jima. We modeled the observed displacements. In order to take topographic effects into account, we applied a finite element method (FEM) using the software Flex PDE Professional version 6.40. We set entire FE domain as 100×100×50 cubic kilometers (129.7011–130.7351˚E, 29.9911–30.8994˚N, 0–50 km bsl). We set top of the domain as a free surface, and sides and bottom of the domain as fixed boundaries. Since we used stations inside Kuchinoerabu-jima in the present study, topography was introduced in the area within Kuchinoerabu-jima using DEM data provided by Kagoshima prefecture, and elevation of the outside area was assumed to be sea level (zero). We assumed a homogeneous elastic rheology with a shear modulus of 30 GPa and Poisson's ratio of 0.25. We applied a vertical spheroid source model and searched optimal values of horizontal location, depth, equatorial and polar radiuses, and internal pressure change of the source which minimize the RMS between observed and calculated displacements using the forward modeling method. A spherical source with 100 m radius (i.e., both equatorial and polar radiuses are 100 m) was obtained beneath the Shin-dake crater (130.2157˚E, 30.4462˚N) at a depth of 310 m asl (i.e., the uppermost part of the spherical source is approximately 100 m below the crater bottom). The pressure increase of 831 MPa yields volume increase of 90 thousand cubic meters. Taking topographic effects into account allowed the reproduction of large horizontal displacements at western rim of the Shin-dake crater and westward horizontal displacement at KUC14. The location of the obtained spherical source coincide with the demagnetized ellipsoid estimated by Kanda et al. (2010, JVGR). They interpreted that piezomagnetic variation was produced by the pressurized rocks around the aquifer due to the continuous supply of high-temperature volcanic gases in addition to the thermal effect. The obtained spherical source may be corresponding to the pressurized aquifer.

Keywords: Kuchinoerabu-jima volcano, ground deformation, GPS, finite element method

Geodetic Constraints on Post-eruptive deformation of 2014 eruption on Ontake Volcano

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ALOS-2 / PALSAR-2 data revealed that post-eruptive deflation over a small region of Jigokudani crater has been continuing. It started immediately after the 2014 phreatic eruption on Ontake Volcano. This deflation was clearly triggered by 2014 phreatic eruption, so this indicates pre-existing reservoir at the shallow depth beneath Jigokudani crater. In the pre-eruptive stage, hydrothermal fluid should have accumulated in this shallow reservoir. So, InSAR analysis of this deflation signal contributes to understanding pre-eruptive process in the pre-existing reservoir. Our aim is to understand the mechanism of the deflation and to constrain pre-eruptive process in the shallow reservoir beneath Jigokudani crater.

The result of InSAR analysis for pairs corresponding to post-eruptive deformation shows a typical spatial pattern of deflation over Jigokudani crater during 2014-2016. Characteristics of inversion result using half-space point source are as follows. Depth of deflation source ranges between 400-750m beneath Jigokudani crater. Total amount of volume change of the source is 6-7×$10^5 m^3$ during 2014-2016. In order to evaluate topographic effects on ground deformation which might be significant in the region with complex terrain, we built a three-dimensional finite element model of Ontake Volcano. We carried out finite element computation and found that topographic effect is negligible from viewpoint of estimating source depth and the amount of volume change.

Assuming that the post-eruptive deflation is caused by discharge of hydrothermal fluid accumulated in the pre-existing reservoir, total mass of hydrothermal fluid emitted from the shallow reservoir, corresponding to the amount of volume change of the deflation source, is less than that of plume emitted from vents during September 2014-November 2014. This indicates that a large part of water mass emitted from eruptive vents must be originated from not the deflation source but deeper part of Ontake Volcano.

Assuming that accumulation of hydrothermal fluid inside the deflation source was triggered by 2007 dike intrusion event, an increase of GNSS baseline length between Otiai- Tanohara must be 3 cm during 2007-2014, but actually, such increase has not been observed. This suggests that accumulation of hydrothermal fluid inside the deflation source of the 2014 eruption almost completed by 2007 eruption accompanying dike intrusion event.

Keywords: Ontake Volcano, Phreatic Eruption, InSAR, Ground Deformation

Volcanic deformation of Atosanupuri volcanic complex in the Kussharo caldera, Japan, from 1993 to 2016 revealed by JERS-1, ALOS and ALOS-2 radar interferometry

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1. GSI of Japan, 2. Hokkaido Univ., 3. Kyoto Univ., 4. JAXA

A series of inflations and deflations of a volcanic complex in the Kussharo caldera, eastern Hokkaido, Japan, was revealed by interferometric analysis using archived satellite synthetic aperture radar data. A time series of interferograms from 1993 to 1998 showed the evolution of a ground deformation process. The horizontal dimension of the deformation field is about 10 km in diameter, and the largest amplitude of the deformation is approximately 20 cm. The inflation occurred in 1994 and a simultaneous earthquake swarm activity was observed just around the inflation area, however, there was no other observation related to the deformation. The inflation was then followed by a deflation and the deflation is a mirror image of the inflation. Model simulations suggest that the deformation was caused by a source at a depth of about 6 km and the position of the source did not change throughout the episode. In addition to the main sequence of the inflation-deflation, there is a smaller scale deformation structure at the center of the deforming area. The small scale and constant rate deformation on lava domes was still observed 20 years later by a new satellite.

Keywords: Kussharo caldera, Atosanupuri volcanic complex, Volcanic deformation, InSAR, JERS-1, ALOS, ALOS-2

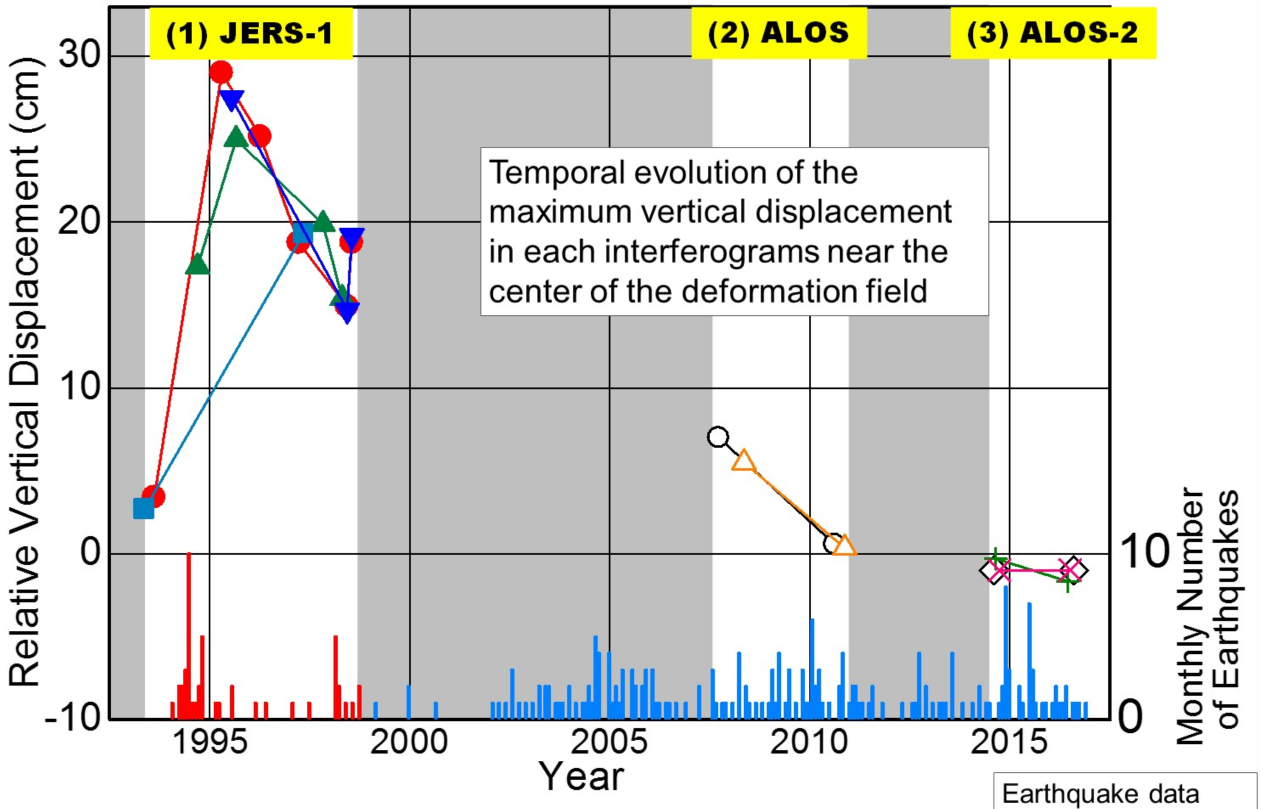

Fig. 1 Series of inflation and deflation

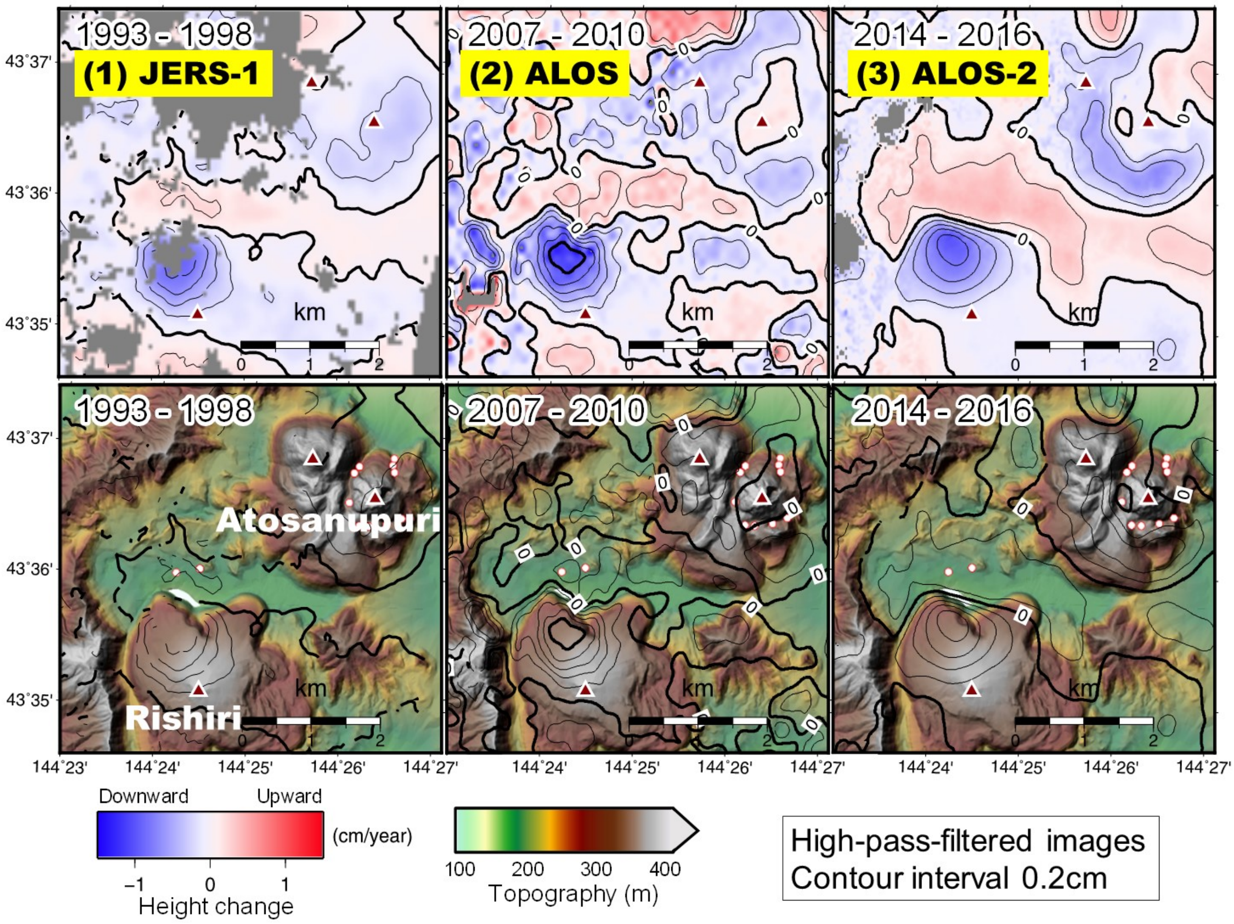

Fig. 2 Average images of small scale deformation

Ground Deformation at Campi Flegrei caldera, Italy, revealed by InSAR analysis of ALOS-2/PALSAR-2

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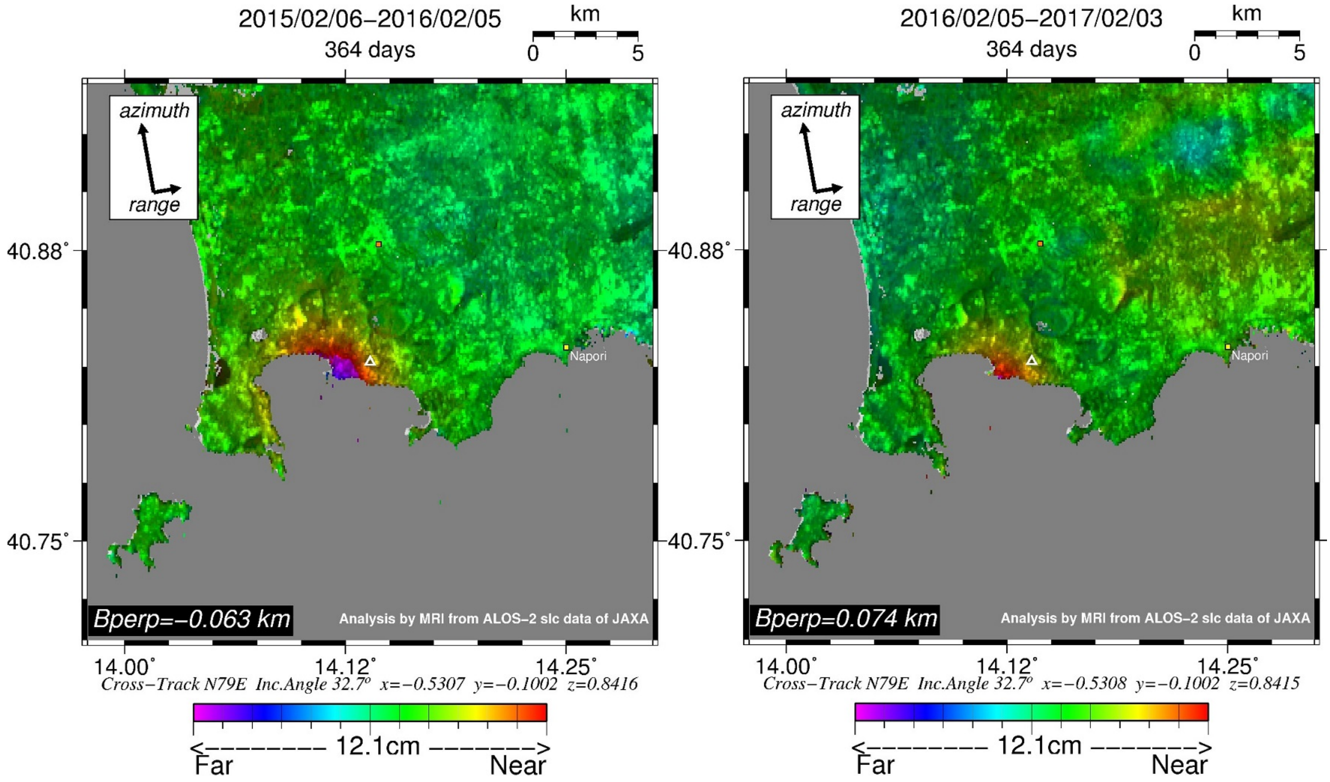
Campi Flegrei caldera in Italy is also close to the metropolitan area of Naples and is one of the regions with the world's highest volcanic risks. The most recent eruption continued for 8 days in 1538 when Mt. Monte Nuovo was formed (VEI = 3). Since then, no eruption has occurred for about 500 years, but expansion and contraction of ground deformation have been reported frequently by GNSS analysis and interference analysis using SAR satellites (for example, Lundgren et al. (2001) And Troise et al. (2007)). Recently, several data showing expansive crustal deformation around Pozzuoli Bay have been reported and it is suggested that active volcanic activity is still continuing (Martino et al. (2013) and D 'Auria et al. (2015) etc). In addition, Chiodini et al. (2016) suggest that magma could be approaching the critical degassing pressure at Campi Flegrei and where accelerating deformation and heating are currently being observed.
ALOS-2, was launched on May 24, 2014, has an L-band SAR (PALSAR-2) and survey all over the world. We performed interferometry analysis using ALOS-2/PALSAR-2 data surveyed after 2014, detected the ground deformation of Campi Flegrei caldera, and tried estimating underground pressure source. As a result, it was found that the ground uplift of about 10 cm was detected in the interferometry analysis of the both orbit between 2015 and 2016, and the ground deformation can be explained by assuming a Mogi point source of about 4.6×10^6 m^3 to about 3.8 km below the sea level. Furthermore, the InSAR analysis using pairs from 2016 to 2017 also detected the displacement up to about 6 cm toward the satellite can be seen around Campi Flegrei caldera, suggesting that the ground uplift is continue.
PALSAR-2 data were prepared by the Japan Aerospace Exploration Agency (JAXA) and were shared within PALSAR Interferometry Consortium to Study our Evolving Land surface (PIXEL). PALSAR-2 data belongs to JAXA. We would like to thank Dr. Ozawa (NIED) for the use of his RINC software. In the process of the InSAR, we used Digital Ellipsoidal Height Model (DEHM) based on the Shuttle Radar Topography Mission (SRTM 4.1) provided by Consortium for Spatial Information (CSI) of the Consultative Group for International Agricultural Research (CGIAR), and Generic Mapping Tools (P.Wessel and W.H.F.Smith, 1999) to prepare illustrations.

Keywords: ALOS-2/PALSAR-2, InSAR, Campi Flegrei caldera, Ground deformation


2015/02/06–2016/02/05
364 days
km
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Bperp=–0.063 km
Analysis by MRI from ALOS–2 slc data of JAXA
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Cross–Track N79E Inc.Angle 32.7° x=–0.5307 y=–0.1002 z=0.8416
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Napori
Bperp=0.074 km
Analysis by MRI from ALOS–2 slc data of JAXA
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Cross–Track N79E Inc.Angle 32.7° x=–0.5308 y=–0.1002 z=0.8415
<––––––––– 12.1cm ––––––––>
Far
Near

Monitoring volcanic activity from space by ALOS-2 (Daichi-2) / PALSAR-2 data

*Masaki HONDA[1], Yuji Miura[1], Yasuaki Kakiage[1], Haruka Ueshiba[1], Hiroyuki Nakai[1], Basara Miyahara[1], Yu Morishita[1], Tomokazu Kobayashi[1], Hiroshi Yarai[1], Satoshi Fujiwara[1]

1. GSI of Japan

The Geospatial Information Authority of Japan (GSI) has conducted to monitor ground surface deformation of earthquake, volcanic activity, subsidence and landslide throuhtout Japan by interferometric SAR (InSAR) analysis using ALOS-2 (Daichi-2) /PALSAR-2 data.
ALOS-2 is routinely observing the whole area of Japan both in ascending and descending orbits three to four times a year following basic observation schedule designed by JAXA. Every time observation data is newly acquired, GSI always conducts InSAR analysis of the data combined with the former data which have the same path and the same observation mode. In the sequence of the analysis, we also conduct tropospheric error reduction with numerical meteorological model of Japan Meteorological Agency (JMA) and reduction of long wavelength error with GNSS solutions of GNSS continuous observation system (GEONET).
Images obtained from InSAR analysis (hereinafter referred to as "SAR interferogram") are formated into tile data, and can be browsed on a web map of GSI, "GSI Maps". GSI Maps enables us to superimpose SAR interferograms on various geospatial information provided by GSI such as topographic maps, aerial photographs, volcanic land condition maps and so on. This visualization enable us to easily compare SAR interferograms to other information like topography and geology and more robustly identify an area of ground surface deformations on the SAR interferograms.
We are monitoring 97 volcanoes in the domestic land including the Northern Territories using SAR interferogrms of ALOS-2 and reporting crustal deformation detected by the interferograms to regular meetings of the government expert committee, Coordinating Committee for the Prediction of Volcanic Eruption. In addition to the regular observation, in case of significant activities of volcanos such as eruptions, urgent observation of ALOS-2 is requested to JAXA by Volcano WG (JMA for the secretariat) of the demonstration experiment for disaster prevention by Earth Observation Satellite. If the urgent observation is conducted based on this request, GSI emergently analyzes the data, provides the SAR interferograms to Coordinating Committee for the Prediction of Volcanic Eruption and open the interferograms to the public as necessary.
In this presentation, we report monitoring of ground surface deformation, especially monitoring of volcanoes, by InSAR analysis using ALOS-2 data, which the GSI is working on.

Keywords: InSAR, ALOS-2, monitoring ground surface deformation, volcanic activity

MODVOLC - monitoring Earth's sub-aerially active volcanoes from space since 2000

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1. University of Hawaii at Manoa

The MODVOLC system (http://modis.higp.hawaii.edu) uses the two MODIS sensors carried onboard NASA’s Terra and Aqua satellites to monitor the Earth’s volcanoes for evidence of thermal unrest. Primarily sensitive to the presence of active lava, the system has detected, monitored, and recorded the thermal emittance from eruptions at 107 volcanoes since the system became active in February 2000. This presentation will cover, 1. How the algorithm works and the re-designed webpage that allows anyone to access and interrogate the global 17 year archive; 2. Some interesting results that have been obtained from analysis of the data including evidence for periodicity in eruptions at some volcanoes, and general differences in magnitude and intensity of thermal emission from lava domes, flows, lakes and fountains.

Keywords: Remote sensing, volcanology, MODIS

Integrated offshore investigations in the vicinity of Kikai Caldera, southwestern Japan ―towards a comprehensive understanding of destructive caldera eruptions―

*Hiroshi Ichihara[1,2], Jumpo Hashimoto[1], Yamato Takahashi[1], Satoshi Shimizu[1], Mamoru Sano[1], Tetsuo Matsuno[1], Nobukazu Seama[1], Yojiro Yamamoto[2], Hikaru Iwamaru[1], Kazuo Nakahigashi[1,3], Nobukazu Wakabayashi[1], Shuichi Kodaira[2], Yoshiyuki Tatsumi[1]

1. Kobe University, 2. Japan Agency for Marine-earth Science and Technology (JAMSTEC), 3. Tokyo University of Marine Science and Technology

Integrated offshore geophysical and geological investigations have been started to understand the mechanism of catastrophic caldera-forming eruption (CCFE) of the Kikai Caldera, SW Japan, which caused the latest CCFE on the Earth at 7.3ka. This caldera has been focused as it is a submarine caldera allowing to conduct dense seismic structural survey that is required for imaging and monitoring a large magma reservoir beneath this caldera. In the Oct. 2016, Kobe University and JAMSTEC conducted bathymetric survey with multi narrow beam echo sounder (MNB), geomagnetic survey with a proton magnetometer, multi-channel reflective seismic survey (MCS), and deployments of ocean bottom seismometer (OBS) and electro-magnetometer (OBEM) in "the 1st KOBEC exploration cruise" by the training vessel "Fukae-maru "belonging to Kobe University. The MNB survey revealed detailed bathymetry in the vicinity of the caldera. The bathymetric change from data obtained in the past bathymetric survey by Japan Coast Guard (2008) will be discussed in the presentation. In addition, acoustic pressure anomalies within the seawater rooting to the seafloor observed at the several areas in the margin and inside of the caldera. They are interpreted as hydrothermal anomalies relating to volcanic activities. The MCS surveys were conducted beneath 4 survey lines across the caldera. The reflection profiles show dense layered subsurfaces outside of the caldera while reflective planes are hard to be recognized inside of the caldera. Faults and disconformities are recognized in the several locations. Preliminary geological interpretation will be also discussed in the presentation. The OBSs and OBEMs will be retrieved in the 2nd exploration cruise in March 2017 by "Fukae-maru". In the 2nd cruise, we also plan to conduct direct seafloor observation by a remotely operated vehicle (ROV) named "Shindai-2K". In addition, we will deploy 4 OBEMs which equip absolute pressure gauge to detect vertical geodetic displacements and to image electrical resistivity structure which may reveal magma reservoir beneath the caldera (e.g. Hill et al., 2009).

K-Ar age connected with initial Ar isotopes and anomalous noble gas isotope ratio, observed in eruption

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The ZAO volcano, which is classified stratovolcano volcano, is located the central Northeast Japan area, and has been active since ca. 1 million years ago approximately. The newest stage started about ca. 35ka. Pyroclastics dominate in this stage. They are further classified into 5 parts: the Kumanodake pyroclastic rocks, the Komakusadaira pyroclastic rocks, the Kattadake pyroclastic rocks, the Umanose agglutinates, the Goshikidake pyroclastic rocks. this newest The volcanic products in the newest stage are classified into medium-K and calc-alkali series of basaltic andesite to andesite, which are regarded to be formed by mixing between felsic and mafic magma in many cases (e.g. Takebe et al., 2015).

The un-spiked Potassium-Argon dating (sensitivity method, i.e. peak-height comparison) can be combined with comprehensive noble gas analysis protocol. When the magma (melts) solidify, it is critical that the initial Ar isotope ratio reaches equilibrium with atmospheric composition. In case that disequilibrium and/or kinetic effect are suggested from isotopic fractionation resulted to the altered initial Ar isotopic ratio from recent atmosphere, the corrected initial isotope ratios were applied to the calculation using with un-spiked K-Ar method. Although Kaneoka (1980) reported that the chemical composition of igneous rock and eruptive condition affect to the noble gas composition, there is a little example of analytical data. Thus, it is necessary to confirm the noble gas isotopic ratio and abundance.

The Zao magmatism of newest volcanic products was reported in Takebe et al. (2009); the respective K-Ar ages of the Komakusadaira pyroclastic rock, the Kattadake pyroclastic rock, Umanose agglutinate is about 30-57ka (one outlier is 100ka), 13ka and 5ka. The newest volcanic products of Zao volcano (the Goshiki pyroclastic rock, the Komakusadaira pyroclastic rock) including historic lava and the neighboring hot spring waters were analyzed by standard noble gas analysis method. We selected and analyzed both low bubbled and high-bubbled sample from each stratigraphy. The noble gas isotopic analysis is performed by noble gas mass spectrometer, GVI-5400He (GV Instruments Co.), in JAMSTEC. We contrived to reduce the atmospheric contamination to sample by using the 60-80 mesh size usually applied to the K-Ar dating. The He isotope ratio was calibrated by the Kaminoyama hot spring gas collected in 1983 (Hanyu and Kaneoka, 1987; Kumagai 1999, Tamura et al, 2005). As the working standard for reference of heavier noble gases for 20ka and older, the age standard samples of YZ-1 (227ka; e.g. Takaoka, 1989; Nagao et al., 1991) from Zao volcano and of MZ-94 (326ka; Iwata et al, 2009) from south Zao volcano were applied.

In terms of the heavier noble gases than Ar, i.e. Kr, Xe, their isotope ratio is similar to the atmospheric ratio; however, their abundance is much concentrated i.e. 10-100 times higher than the atmospheric abundance, even the. Kr and Xe isotopic ratio of YZ and MZ94 having significant anomaly contrasted to the atmospheric ratio. Otherwise, we tried to find the contribution from magmatic composition using He isotopic ratio. Therefore, we tried to clarify any contribution from surface environment for magmatic noble gas in the newest volcanism of Zao volcano.

Keywords: Zao, volcano, K-Ar dating, isotope ratio, Helium

Eastimate of alkalie basalt magma H_2O content in Kannabe volcano

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1. Introduction
Alkaline basaltic volcanism widely occurred in the Chugoku area, southwestern Japan, from Paleogene to Quaternary. Although major, trace, and isotopic compositions of these volcanic rocks have been intensively analyzed, detailed magma differentiation processes have not been examined on the basis of a petrologic study. Here, we conducted thin section observations and determined bulk-rock and mineral compositions of Quaternary-Kannabe alkaline volcanic rocks in order to reveal crystallization differentiation process. Consequently, we concluded that H_2O content in Kannabe magma was ˜1.6wt%, which is half as low as the estimation in the previous study.
2. Kannabe volcano : Hidaka Lava, Arakawa Lava, Jugo Lava, Shiwagano Lava
Eruption age of Kannabe volcano acted between 25ka˜7.3ka because Kannabe volcano is sandwiched between AT and K-Ah tephra. Kannabe volcano consists of four lava flows erupted from different volcanic centers: Hidaka Lava, Arakawa Lava, Jugo Lava, and Shiwagano Lava in order of age. Bulk-rock SiO_2 contents of Hidaka, Arakawa, Jugo, and Shiwagano Lavas are 48.8-49.1 wt%, 48.9-50.0 wt%, 49.3-50.1 wt%, and 48.8-50.0 wt%, respectively, and MgO contents of those lavas are 6.8-7.1 wt%, 6.5-6.9 wt%, 6.5-6.6 wt%, 6.5-7.2 wt%, respectively. MgO contents monotonically decrease from Hidaka Lava, through Arakawa Lava, to Jugo Lava, whereas Shiwagano Lava covers whole compositional range of the other three lavas. Compositional trend of major elements observed for four lavas can be reproduced by fractional crystallization of olivine, clinopyroxene, plagioclase, and titanomagnetite.
Four lavas have relatively small amount of phenocrysts (<˜10vol%). Most of those phenocrysts is olivine. Glomeroporphyritic structure of olivine and plagioclase was confirmed. Olivine which has kink band was not confirmed. All phenocrysts shew normal zoning from analyses of Electron Probe Micro Analyzer, and observation of backscattered electron image. Cores of olivine and plagioclase phenocrysts shew Fo# [=100Mg/$(Mg+Fe)_{mol}$] = 70˜86 and An# [=100Ca/$(Ca+Na)_{mol}$] = 60˜78, respectively. Cores of plagioclase phenocrysts have two peaks of An# = 78 and 66 in the frequency diagram of An#. The plagioclase phenocryst of An# = 66 is pure and shows euhedral, but the plagioclase phenocryst of An# = 78 has pollution zone inside it. On the other hand, olivine and plagioclase of glomeroporphyritic structure shew Fo# = 76˜78 and An# = 64˜68, respectively. This result suggest that the plagioclase phenocryst of An# = 78 is not a phenocryst crystllized from same magma.
3. Consideration : Estimate of Hidaka Lava magma H_2O content
We estimated magma H_2O content for Hidaka Lava, which have the most MgO content in the four lavas and small plagioclase phenocryst volume (<˜1vol%), using a combination of these bulk compositions, plagioclase-liquid hygrometer (Lange *et al.*, 2009), and a geothermometer for olivine-saturated melts (Sugawara,2000 ; Medard and Grove,2008). When the pressure is 0.5GPa, 1.0GPa, the magma H_2O content is 1.3 wt%, 1.6 wt%, respectively. These results are less than magma H_2O content estimated by Zellmer *et al.* (2014). This cause is that Zellmer *et al.* (2014) estimates magma H_2O content using plagioclase which is not phenocryst and shows An# = 82.

Keywords: magma water content, the Chugoku area, alkalie basalt

Magma plumbing system of Fuji volcano inferred from product of latest summit eruption (Yufune-2 scoria)

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Because of no recent eruption in Fuji volcano, syneruptive geophysical observations have not constrained magma plumbing system. Petrological studies of past eruptive products thus have an important role. As a target, I have selected a latest summit eruption, 2200 years ago. Yufune-2 scoria, product of this eruption, has an eastern dispersal axis (Miyachi, 1988). Scoria samples were collected from an outcrop locating 10 km to the east of the summit. I have divided the scoria deposit into 5 units (a-e; 10, 90, 5, 15, 60 cm thickness, respectively), each of which is distinctive in scoria size. The scoria size increases upward between unit-a and unit-b, but decreases in the upper units. The change in scoria size implies those of eruption intensity and eruption column height, if wind direction and intensity did not change. Bulk rock composition of scoria (50.5-51.2 wt. % SiO_2) does not change with eruptive unit. To further characterize erupted basaltic magma, I have analyzed thin sections of 4-6 scoriae for each unit.
Except the xenolith of basaltic lava included in scoriae of unit-a (Suzuki and Fujii, 2010 JVGR), scoriae seem almost homogeneous regardless of the eruptive unit. Phenocrysts of olivine and plagioclase (less than 2mm) are euhedral and lack in reaction rims. As a whole eruption, Fo contents of olivine cores vary between 73 and 80, while An contents of plagioclase cores vary between 65 and 92. Core compositional distribution is distinctive in each unit. All scoriae of unit-b and c are dominated by low-Fo (<76) and low-An (<85) cores. On the other hand, unit-e scoriae and half of unit-d scoriae are characterized by cores of high-An (>85) and high-Fo (>76), although some scoriae show wide Fo variety extending to Fo73. In unit-a scoriae and rest of unit-d scoriae, cores of phenocrysts show wide compositional range (Fo73-80, An65-92). As a whole, rim compositions of phenocrysts have correlation with compositional distributions of phenocryst cores.
Phenocrysts are divided into two types depending on dominant core composition. High Fo (>76) olivine and low Fo olivine (<76) have no overlap in composition and have similar crystal size. High An plagioclase (>85) has homogeneous core and is characterized by small crystal size (less than 500 μm). On the other hand, low An plagioclase (<85) rarely includes high An (>85) region in the center of the core. The high An (>85) region resembles the high An type in size. Scoria only with high Fo olivine and high An plagioclase (e.g. unit-d) have clearly lower amount of phenocrysts (3 vol. %) than scoria with only low Fo olivine and low An plagioclase (e.g. unit-b, c; 18-19vol. %).
These lines of evidence indicate that 1) magmas with different degree of crystallization (two endmembers), but with the same bulk composition, were present in the magma plumbing system just before the eruption, and 2) the two endmembers were erupted independently or mixed. Mixed magma erupted in unit-a. Then, the high-crystallinity part erupted without mixing in the climax (unit-b and unit-c). In the ending stage (unit-d and unit-e), less-crystallized magma erupted, accompanied by mixed magma. It is highly possible that the high crystallinity magma was derived from the less crystallized magma, judging from the continuous core composition of phenocrysts. I could identify the parts that crystallized when crystallinity was low only for plagioclase, not for olivine This can be explained by much more sluggish diffusion of CaAl-NaSi in plagioclase in comparison with Mg-Fe in olivine. More examination of diffusion profiles (including other elements) is necessary in order to constrain the timescale from the generation of high-crystallinity magma to the final ejection. It is also important to discuss the storage depths of two endmember magmas by the H_2O analyses of melt inclusions in phenocrysts (Yasuda et al., 2014) . At present, only rough estimation is available. Near-liquidus coexistence of olivine and plagioclase in the

melt of the groundmass composition requires less than 2.5kbar and H_2O content of ca. 1.5wt.%, and 1110-1120C, if QFM buffer is assumed.

Keywords: Fuji volcano, Yufune-2 scoria, Magma plumbing system, Phenocryst size, Phenocryst abundance, Magma mixing

Tilt and Volumetric Strain change observed around Lake Akan at November 24, 2016

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Integrated hypocenter database prepared by Japan Meteorological Agency (JMA) shows slight increase in number of earthquakes around Mt.Oakan in November, 2016. On November 24, earthquakes with low frequency component is observed continuously, which is followed by an earthquake felt at Akan region. Two tiltmeters at Mt.Meakan installed by JMA, on the other hand, showed tilt change synchronously with the earthquakes with low frequency component. Their magnitude and down-dip direction are in the order of 10^{-8}rad and northeast (toward Lake Akan and Mt.Oakan).

Such change were also observed at other stations around the region, namely, groundwater level sensor at Lake Akan (AK3: installed by GSH and Hokkaido Univ.), Sacks-Evertson strainmeter at Kussyaro (KUT: installed by Hokkaido Univ.) and Accelerometer at Hi-net station "Akan-Kita" (ANNH: installed by NIED). Takahashi et al. (2012) reports that the groundwater level around Mt.Meakan acts as volumetric strainmetor, hence we converted the groundwater level change to volumetric strain change accordingly. It should be noted that volumetric stain change at AK3 and KUT both show the compressive strain.

We estimated the pressure source from these observations assuming a deflating point source. The source is estimated at the south of Mt.Oakan. Its depth and volume change are estimated to be 15km and 2×10^{6} m^3. Due to the NE-SW-wide distribution of the stations used for the estimation, the error in horizontal position of the source is larger in NW-SE direction. The deep source depth is required to explain the compressive strain at KUT, which is 20km away horizontally from estimated source, for the deflating point source exhibits compressive strain at region where $r<1.4D$ (r and D being horizontal distance from the source and source depth, respectively).

Keywords: Akan, tilt change, crustal deformation

An application of the ASL method to seismic activity at Tokachi-dake

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Hypocenter distribution of volcanic earthquakes in time and space is one of the important information in assessing volcanic activity. Low-frequency earthquake (LP events) and continuous tremor often occur at shallow part of volcano edifice. Those events are considered to have close relationships with volcanic fluids such as magma, water, and steam. However, since phase arrival times of those events are usually obscure, it is challenging to determine the hypocenter automatically.
Tokachi-dake volcano in Hokkaido has a number of LP and tremor events, along with increase in volcanic activity. To obtain precise hypocenter location of these events at Tokachi-dake, we adopt Amplitude Source Location (ASL) method (Battaglia and Aki, 2003). The ASL method is one of the hypocenter determination techniques that analyzes the amplitude ratio of seismic wave among different stations under the simple assumption on distance attenuation and isotropic radiation of high-frequency seismic signal. Since the ASL method doesn’t require precise picking of seismic wave arrivals, it is potentially effective for hypocenter determinations of LP events and continuous tremor.
For introducing an assumption of isotropic radiation of seismic waves, the ASL method usually treats high-frequency signals over than 5Hz. Since such high-frequency seismic signals strongly are affected by a shallow ground structure, we first estimate site amplification effect at each station at Tokachi-dake by using coda normalization method (e.g., Phillips and Aki, 1986). We used 10 local earthquakes that occurred around Hokkaido in 2013-2016, and estimated site amplifications at 8 seismic stations, including 3 stations operated by Hokkaido University. Site amplification factors at Tokachi-dake clearly increase around Taisyo and 62-2 craters. Then we tried to determine the source location of volcanic earthquakes using the ASL method. As a preliminary analysis, we assumed the hypocenter locates at a shallow part of the volcano, and performed two-dimensional search of epicenter by fixing a source at the surface of topography. Consequently, estimated epicenters of tested events are well distributed around 62-2 crater. This result roughly matches the hypocenter distribution reported by JMA. The spatial distribution of estimation error should be examined at first. Then we will extend the searching algorithm in depth direction to estimate more detailed source locations.

Keywords: ASL method, Tokachi-dake, volcanic earthquake

Comparison between crustal movement and seismicity in Izu Ohshima Island

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We observe not only a long period dilatation of a baseline but also a periodical contraction and dilatation of baseline in Izu Ohshima Island. We observe micro earthquakes around Izu Ohshima Island too. So, we compare between earthquake occurrence and baseline length.
We use JMA hypocenter catalogue from April,2002 to January,2017. The number of earthquakes are 9969. We check Magnitude-Cumulative plot. Then, we find good determination of earthquake larger than Magnitude 1.0. We use baseline length from GSI 96054 to GSI 96055. We average baseline length in each month. We count earthquakes in each month.
When we count earthquakes number in each month, sometime earthquakes number are large. 7 months are larger than 100 earthquakes. We divide 4 period in baseline. A is bottom to middle. B is middle to peak. C is peak to middle. D is middle to bottom. 4 months larger than 100 earthqukes are in period B. 3 months larger than 100 earthqukes are in period C. This means earthquake swarms occur in dilatation period.

Keywords: Izu Ohshima volcano, crustal movement, seismic activity

Characteristics of multi-component strainmeter in Izu-Oshima for medium to long term variation -- strain data comparison with GNSS observation --

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In order to study about volcanic deformation in Izu-Oshima, we installed a multi-component strainmeter in a borehole at SNB station located in the southwest part of the island in 2013. The depth of strain sensors is about 75m from the ground level, or 25m below the sea level. The instrument has four strain sensors oriented 45 degrees apart and measures horizontal linear strains in N34.2E, N10.8W, N55.8W and N100.8W as CH0 to CH3 respectively. Accumulated data of SNB strainmeter make it possible to research about characteristics for medium to long term strain variation. In this study, we compared the data with two kinds of reference strain field, one is estimated from GNSS observation and the other from a spherical pressure source model. For observation by a borehole strainmeter, it is important to know the instrument's response to the surrounding crustal strain variation. Comparison with the reference field is an effective tool for that.
For the data of the strainmeter at SNB, abnormal steps are corrected, as well as tidal strain and the effect of atmospheric pressure change. The first reference stain is estimated from GNSS positioning data of three stations within about 4 km from SNB. Average strain field near SNB is derived from the relative displacement of those GNSS stations as strain components e_{xx},e_{xy} and e_{yy} for each day, and linear strains corresponding to CH0 to CH3 of the strainmeter are calculated by coordinate transformation. The other reference stain is estimated from a spherical pressure source model. In Izu-Oshima, volcanic deformation in medium to long interval is approximated to the deformation caused by a spherical pressure source located underground. The accompanied strain at an arbitrary point can be calculated from the source parameters, the position and the volume change. From GNSS observation all around the island, MRI (2017) estimated the position of the pressure source, and also its volume change as time series, from which we calculated the strain fields at SNB. Comparing those two reference strains, CH1 components of both strain were very similar as well as CH2 in long term trend and variations of the period about a year for the interval from 2012 to 2016. It seems the strain estimation is good for these components.
Strain fields of CH1 and CH2 observed by the SNB strainmeter were inspected using the referenced strains. In CH2 data of SNB, we found a continuous long term extension and repeated contraction and extension of the period 1 to 1.5 years. They were very similar to those of the references, the maximum and minimum of the strain data occurred almost in the same days respectively. Their variation from 2014 to 2015 were about 6 micro-strain in amplitude for the strainmeter, about 4 for the estimation from GNSS and about 8 for the estimation from the pressure source. The similarity means that each strain data or estimation is roughly reliable. Contrary in CH1, we could not find the similarity in the variation of the period from 1 to 2 years. The comparison with the reference strain estimated from the GNSS observation nearby and the spherical pressure source model made it clear that CH2 of the strainmeter could be acceptable in monitoring of the medium to long term volcanic deformation of Izu-Oshima.

Keywords: Izu-Oshima Volcano, strainmeter, GNSS

Volcanic deformation caused by gas bubbles rising in the magma chamber: Application to periodic deformation at Izu-Oshima volcano

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Recent geodetic observation networks were succeeded in detecting volcanic deformations with high time-resolution in active volcano. These data can be used for understanding the volcanic activities. In this study, we present the temporal changes of volume increase of magma chamber due to gas bubble rising and try to apply it to volcanic deformation at Izu-Oshima volcano.
In a magma chamber, small gas bubbles rise due to their buoyance force. As the gas bubbles rise, the gas bubbles expand due to pressure difference between gas bubbles and surrounding melt. As the expansion of gas bubbles, the volume of magma increases. The amount of volume increase of magma chamber is depended on the ratio of bulk modulus of melt and rigidity of surrounding elastic medium. The gas bubbles rise in the magma with a velocity proportional to the square of the gas bubble radius. We calculate the temporal changes of the volume changes of magma chamber, assuming the initial condition that the gas bubbles homogeneously distributed in the magma. The results show that the volume of magma chamber increases with constant rate, at first. Then the rate of volume change gradually decrease with time.
We compare these results and volcanic deformation detected by GNSS observation network at Izu-Oshima volcano. The pressure source of this deformation was estimated at a depth of 4-5 km below sea level and the amount of volume increase of 10^6 m^3. Considering the gas bubble radius of 2×10^{-4} and the number density of gas bubbles of 10^8 m^{-3}, the amount of volume changes and time scale of volcanic deformation observed at Izu-Oshima volcano was expressed.

Keywords: volcanic deformation, Izu-Oshima, gas bubble

Intermittent volcanic tremor activity at Miyakejima volcano during April 2015 –March 2016

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Volcanic tremor is considered as a seismic signal generated by complex interactions of magmatic fluids with surrounding rocks, so that it provides clues to understand underground volcanic situations. Intermittent tremors began to occur beneath Miyakejima volcano in April 2015. After a quiet period of three months, the tremor activities increased in amplitude until December, and then rapidly decreased at the end of December, following with weakened intensity until March 2016. Even during a quiescent stage, volcanic tremor has appeared occasionally, however, this tremor episode shows a very regular and rhythmic pattern. We have investigated the tremor waveforms based on the Izu-Islands volcanic observation system operated by the Tokyo metropolitan government, using a time series and spectral analysis in conjunction with determination of tremor sources. During tremor episodes, the durations of bursts were about 5 min, while the intervals between the beginning of a burst and the onset of the next one were from 15 to about 17 min. The tremor sources were located beneath the crater south rim at a depth of about 1.2 km, where low frequency events were also located. The dominant frequencies of tremors were 3 to 5 Hz, similar to low frequency events. The relationship between the characteristics of the tremor and rainfall and tidal effects implies the involvement of a hydrothermal system under the crater. On the basis of all these results and similarity to a geyser, we propose a conceptual model to interpret this tremor mechanism.

Keywords: intermittent volcanic tremor , Miyakejima, geyser

Evaluation of Recent Activity at Miyakejima and Increase of Volcanic Gas Discharge in May 2016

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At Miyakejima, the volcanic activity has gradually declined in since the 2000 eruption, and no eruption occurred after January 22, 2013. At the same time, the volcanic gas (sulfur dioxide) emission rate which was beyond 10,000 tons per day at peak also decreases, and now decreased to near the detection limit after June, 2016. The thermal activity in the vicinity of the main fumaroles, in the summit crater, shows a tendency to decrease in recent years, and the geothermal areas seems to be narrow from September 2016 onwards.
On the other hand, focus on recent activities, volcanic earthquakes in the shallow location beneath the summit crater occurred steadily, though it's relatively rare. In addition, according to GNSS observation, the relatively long baseline was growing since around 2006, suggesting that magma accumulation in the deep area continues. Also with the short baseline, shrinkage fluctuation since 2000 has passed through the stagnation from around 2013, and has started to be growing in the beginning of 2016.
Under such circumstances, volcanic tremor accompanied by crustal deformation occurred in February and May 2016, and a temporary increase in volcanic gas discharge amount was observed after this phenomenon. Especially the event in May 2016 showed a more obvious change than the other. Some fluctuations in southeast to southward sedimentation were observed by the inclinometer, and the amount of volcanic gas released, which was less than 100 tons per day before the volcanic tremor, increased to 1,200 tons. The volcanic tremor and tilt can be separated in two states. Estimated pressure source by Mogi model, can be explain the contraction source at a somewhat deep position was predominant at first, next then the inflation source just under the crater was increased. And the position of the source estimated using the amplitude ratio (Ogiso, 2015) was consistent with the position of the shallow inflation source.

Keywords: Miyakejima, volcano deformation, volcanic gas

Topographic change of the sea floor after the 2013-2015 eruption of Nishinoshima

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Nishinoshima is an insular volcano consisting of basalt and andesite located on the volcanic front of the Izu-Ogasawara arc. The first historic eruption occurred in 1973-1974, forming Nishinoshima Shin-to which was connected to the pre-historic Nishinoshima island later. After about 40 year quite period, on November 20, 2013, the eruption activity resumed in the sea to the southeast of Nishinoshima, shifting from a severe phreatomagmatic eruption to a Strombolian eruption (magma eruption). After the Vulcanian eruption on November 17, 2015, no eruptive activity has been observed. The 2013-2015 eruption event is characterized by the expansion of the area of the island due to extensive lava flow which lasted for two years. As a result, the area of Nishinoshima as a whole became about 2.68 km^2 from about 0.22 km^2 before the activity.
Since the restart of the eruption in November 2013, the Japan Coast Guard has conducted the three cruises for bathymetric survey in 2015 and 2016, as well as monthly-basis airborne observations in cooperation with Tokyo Institute of Technology.
We will present the result of bathymetric surveys around Nishinoshima.

Keywords: Nishinoshima volcano, Bathymetric survey, eruption

Temporal change of sea water composition around Nisinoshima Island accompanying the volcanic activity of Nishinoshima

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Nishinoshima, one of the active insular volcanoes on Izu-Mariana arc, restarted its eruptive activity on November 20, 2013 after 40 years dormancy. A small island was newly appeared at SSE offshore of original Nishinoshima on that day and first lava flowed out from the top of the new island on November 22. Effusion of huge amount of lava continued for two years and original Nishinoshima was merged into the huge amount of new lava flow.

The Japan Coast Guard conducted several investigations around Nishinoshima by survey vessel “Shoyo” and unmanned survey vehicle (USV) “Manbo II” from June 24 to July 7, 2015 and by survey vessel “Shoyo” from May 4 to May 6, 2016, and October 25 to November 3, 2016. Seawater sampling in 2015 was carried out at 21sites 200-875m away from the coast by USV “Manbo II” due to the navigational warning to ships within a radius of 4 km from the new crater of Nishinoshima, while that in 2016 was performed at 8sites by survey vessel “Shoyo” owing to shrinking of the warning area. Measurement of pH and dissolved CO_2 was performed on the survey vessel in the same day. Determination of fluoride, chloride and sulfate was carried out at Kusatsu-Shirane Volcano Observatory.

In a term of investigation in 2015, the volcanic activity of Nishinoshima was very active with lava flow and intermittent strombolian eruption. After December 21, 2015 any eruptive activity hasn’t been observed.

There are no remarkable azimuthal dependence of variation in pH and the concentration of F, Cl and SO_4 of the seawater samples collected in 2015 and 2016. The pH values of seawater samples collected in 2015 were mostly about 8.0 and significantly lower than pH of reference seawater. On the other hand, those of all seawater samples collected in 2016 is about the same value as pH of reference point. This suggests that influence by hydrothermal water appeared in the wide area around Nishinoshima in 2015 and that the influence in 2016 was reduced.

Fluoride concentration of seawater samples collected by 2015 survey was comparable with that of reference sample in 2015, whereas that of seawater samples in 2016 was slightly higher than that of reference sample in 2016. Chloride concentration of seawater samples in 2015 was lower than that of reference sample collected in 2015, whereas that of seawater samples in 2016 was almost same as that of reference sample in 2016. Sulfate concentration of seawater samples in 2015 was higher than that of reference sample collected in 2015, whereas that of seawater samples in2016 was almost same as that of reference sample in 2016. These results indicate that the F/Cl molar ratio of seawater samples in 2015 was higher than that of reference sample in 2015 and that the Cl/SO_4 molar ratio of seawater samples in 2015 was determinately lower than that of reference sample in 2015. The F/Cl molar ratio of seawater samples in 2016 was higher than that of reference sample in 2016 and Cl/SO_4 molar ratio of seawater samples in 2016 was comparable with that of reference sample in 2016. It was inferred from these results that huge amount of thermal water discharged from the volcanic edifice was affected by high temperature volcanic gas. While the influence of high temperature volcanic gas to the thermal water was lessened in

2016. Discolored water generated by reaction between hydrothermal water and seawater is often distributed around volcanic islands and submarine volcanoes. Around Nishinoshima Island, discolored water has been observed all the time of investigation by Japan Coast Guard. Greenish-yellow discolored water was distributed around Nishinoshima in 2015 and bluish-white discolored water was distributed in 2016 according to repeated observation by Japan Coast Guard. The change in the color of discolored water around the island indicates the decline of the hydrothermal activity around Nishinoshima Island.

Keywords: Volcanic islands and submarine volcanoes, Nishinoshima volcano, Discolored water

Cross-correlation analysis of infrasound and seismic signal during the phreatic eruption at Hakone in 2015

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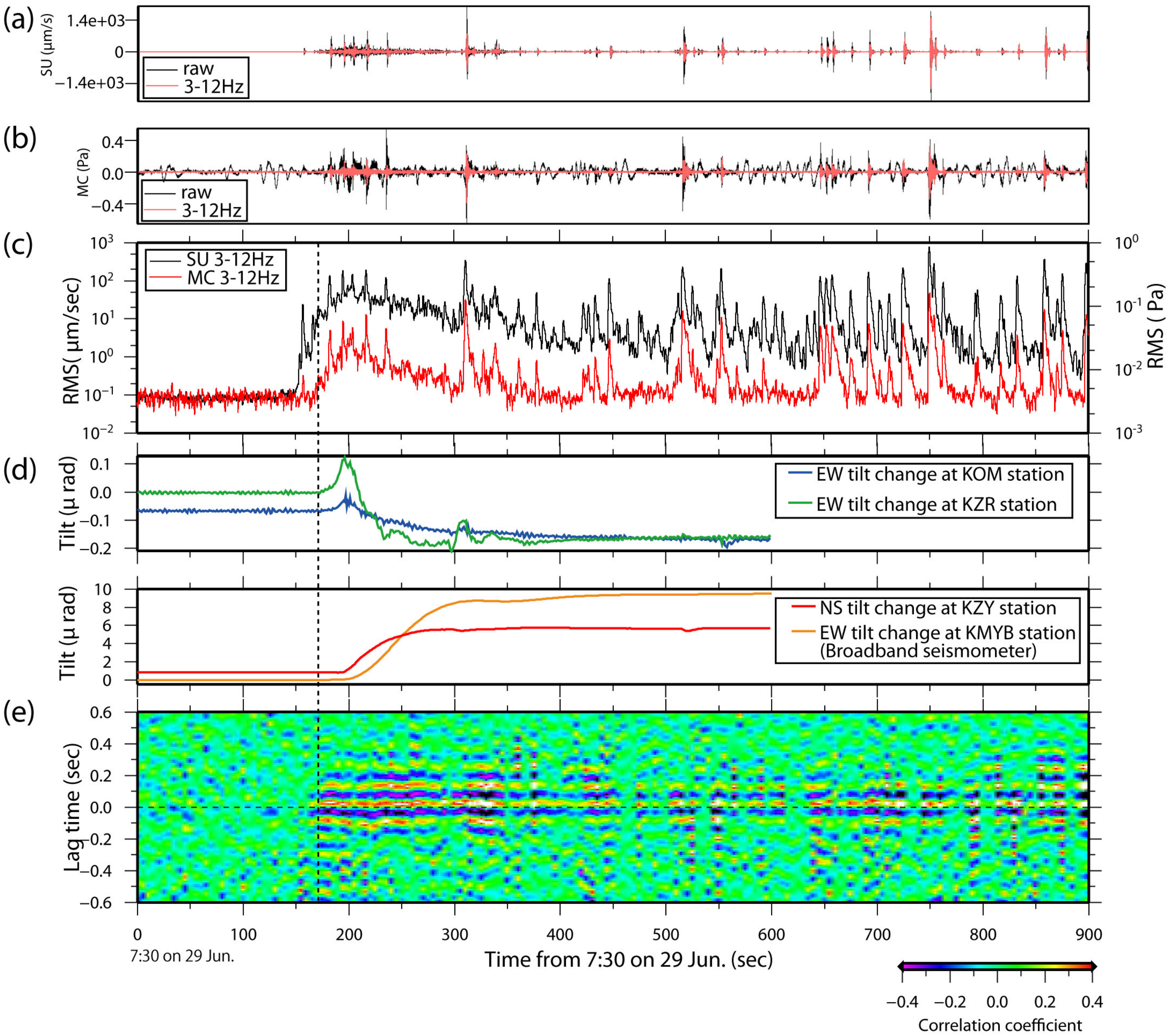
The activity of volcanic tectonic earthquakes in Hakone volcano gradually increased from the end of April, 2015, and small phreatic eruption was observed at Owakidani geothermal region from 29 June to 1 July in this year (Mannen et al., 2015). At the morning of 29 June (at 7:33), abrupt tilt changes of approximately 10 micro radian were detected during two minutes by using tilt meters and broadband seismometers installed around Owakidani geothermal region (Honda et al., 2015). Honda et al. (2015) concluded that these tilt changes could be explained by assuming a shallow open crack source oriented in the NW-SE direction, and they interpreted that hydrothermal fluid of 100,000 m^3 intruded into the region above sea level during the tilt changes. Mannen et al. (2015) reported that volcanic mud flow and ash fall were observed at about 11 and 12 o'clock on 29 June, respectively. However, due to poor visibility around Owakidani region during the eruption, we could not obtain detailed temporal sequence of eruptive activity. In the present study, we conducted a cross-correlation analysis of infrasound and seismic signal to clarify the eruptive activity. Ichihara et al. (2012) demonstrated that infrasonic signals could be identified from a wind noise by using a cross-correlation function of signals from a microphone and a collocated seismometer. We used the waveform record obtained by the microphone and the short-period velocity seismometer at Owakidani station that is located 500m away from the craters. We applied a 3-12 Hz band-pass filter to the infrasonic and UD component seismic signals, and calculated a normalized cross-correlation function of the filtered records, using a 5-s sliding time window. According to Ichihara et al. (2012), significant infrasonic signal can be identified as a pattern of correlation function: the highest peak of correlation function, the negative peak and its node is located around $tau=1/(4f_0)$, $tau=-1/(4f_0)$ and at $tau=0$, respectively, where *tau* is defined as the delay time of seismic and infrasonic signals, and f_0 is the characteristic frequency of infrasonic signal. As a result, we identified the pattern of correlation function in the period from 7:32 to around 10:30 on 29 June, 2015. The appearance time of this correlation pattern is almost coincident with the onset time of the abrupt tilt changes. This result suggests that the emission of volcanic material, such as volcanic gas, started almost simultaneously with the tilt changes, and the infrasonic waves accompanied by the emission generated the ground motion in the immediate area of Owakidani station.

Figure 1 Ground velocity and acoustic signals during the abrupt tilt change on June 29, 2015. (a and b) The raw and the band-passed signals of the vertical component of a seismometer (SU) and a microphone (MC) at OWD station are shown, respectively. (c) RMS amplitudes of the band-passed signals. (d) Examples of tilt records. (e) Normalized cross correlation function of the band-passed seismic and infrasonic signals.

Keywords: phreatic eruption, infrasonic wave


(a)
SU (μm/s)
1.4e+03
0
−1.4e+03
raw
3-12Hz
(b)
MC (Pa)
0.4
0.0
−0.4
raw
3-12Hz
(c)
RMS(μm/sec)
RMS (Pa)
SU 3-12Hz
MC 3-12Hz
(d)
Tilt (μ rad)
EW tilt change at KOM station
EW tilt change at KZR station
NS tilt change at KZY station
EW tilt change at KMYB station
(Broadband seismometer)
(e)
Lag time (sec)
0
100
200
300
400
500
600
700
800
900
7:30 on 29 Jun.
Time from 7:30 on 29 Jun. (sec)
−0.4 −0.2 0.0 0.2 0.4
Correlation coefficient

Influence of volcanic activity in river floor sediment chemical composition around Hakone volcano

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Introduction: More than 100 active volcanoes are distributed in the Japanese archipelago. One of the definitions of active volcanoes is the eruption history from the past 10,000 years ago. There is no historical eruption history, and there are active volcanoes which currently have no fumarolic activity. Even in such an active volcano, there is a possibility of eruption in the future. In considering volcanic disaster prevention, it is important to predict what kind of activities the quiet active volcano will have in the future. Volcanic activity to occur in the future is highly likely to resemble the volcanic activity that occurred in the past. Even in volcanoes where fumarolic activity is not present, identifying the location of past fumarolic activity is useful for predicting future volcanic activity. River floor sediments represent the elemental concentration of the crust surface layer of the upstream area and have been used to create geochemical maps. In active volcanoes, traces of the influence of fumarolic activity that existed in the past may be left in riverbed sediments. In this study, we will take up Hakone volcano where fumarolic activity exists and investigate whether there is influence on Hayakawa mainstream and tributary flow stream sediments flowing around.
Experiment and Operation method: Samples were taken at 19 locations in the main stream and tributary of Hayakawa flowing around Hakone volcano. We gathered approximately 1 kg of river floor sediment with shovels and after having been dried, We put it out for a sieve and got an fine grain (0.30-0.85mm) and coarse grain (0.85-1.7mm). Next, using a magnet, a magnetic substance such as magnetite was removed from the sieved sample, and then ultrasonic cleaning was performed with pure water. This was pulverized in an agate mortar and dissolved using 0.15 mL of a 6 M HClO4 solution and 0.30 mL of a 25 M HF solution. This solution was further allowed to stand at 120 C. for 6 hours and at 170 C. for 6 hours, heated at 200 C. until dry up and allowed to cool. Finally, the sample was dissolved with 5.00 mL of 0.5 M HNO3 solution, and 0.5 M HNO3 solution was further added to the total volume of 25 mL to prepare a sample stock solution. This stock solution was suitably diluted and analyzed by ICP-MS (Thermo Science, iCAP Q).
Results and Discussion: For Hayakawa main stream samples, the concentrations of Sc and V are higher compared to the young crust upper chemical composition in the Japanese archipelago (Togashi et al., 2000), which was matched by the characteristics of volcanic ash excelled areas (mainly East Japan). High concentration of As was detected at the point where the river which flows through the submontane of Mount Hakone and Hayakawa river. It is reported that the As concentration is high in a hot spring that springs off at the central cone of Mount Hakone (Kanagawa Prefecture Onsen geology research center HP). The high concentration As of the river floor sediments discovered this time is thought to be the influence of the volcanic activity of Hakone volcano.
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49-70,33.,p.56-58.

Keywords: Hakone volcano, Geochemical map, Elemental composition

2015-16 year’ s active of Niigata-Yakeyama volcano -seismic activity, volcanic deformation and plume data-

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Niigata-Yakeyama volcano is a small stratovolcano located in the western part of Niigata Prefecture, Japan. Last magmatic eruption occurred in 1773. Recently, Niigata-Yakeyama repeatedly erupt small phreatic eruptions. Japan Meteorological Agency (JMA) has been monitoring the volcanic activity of Niigata-Yakeyama. In 2015-2016, the activity of Niigata-Yakeyama became active. In this paper, we report the seismic activity, ground deformation plume data observed by JMA.

The height of volcanic plume became high since 2015 summer. Ash fall was observed by on-board observation on April and May 2016 (Oikawa et al., 2017, JPGU). By using the plume-rise method, we estimated the heat radiation rate. As a result, it was revealed that the heat radiation rate at Niigata-Yakeyama was increased from May 2016.
The volcano-seismic activity was increased since 2015. The number of volcanic earthquakes rapidly increased from May 1 to 4. The maximum number of volcanic earthquakes per day was 25 on May 1. After that, the number of volcanic earthquakes gradually decreased.
The volcanic deformation was observed by tilt meters and GNSS. The baseline length between Udana and Maruyamajiri extended from January to August, 2016. SAR Interferometry analysis by using ALOS-2/PALSAR-2 data also detected the ground deformation considered as the inflation of Niigata-Yakeyama (Kamata et al., 2016, VSJ). These volcanic deformation data was explained by the pressure source located at the depth of 4-5 kilometers below the summit area of Niigata-Yakeyama volcano and with the volume expansion of 4.9-5.7 $x10^6$ m^3.

These observation data were considered to indicate the intrusion of magma and the activation of hydrothermal activity at shallow part of Niigata-Yakeyama. JMA expanded the observation network for volcanic activity at Niigata-Yakeyama volcano. Two video cameras and one broadband seismometer were installed. JMA continues to monitor Niigata-Yakeyama volcano.

Keywords: Niigata-Yakeyama, seismic activity, volcanic deformation, plume

On the fumarolic activities of Niigata-Yakeyama in early Showa era, and the review of 1949 eruption.

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Niigata-Yakeyama is an active volcano located at southwestern of Niigata Prefecture. The past activities of Niigata-Yakeyama were investigated by Hayatsu(2008). A moderate magmatic eruption occurred in 1773, accompanying pyroclastic-flows. During the 20th century small phreatic explosions occurred in 1983, 1997, and 1998. As of December 2016, fumarolic activities were found to exit on the summit.
At the end of 2015, the fumarolic activities were observed to be high level, the heights of steam plumes were observed to be higher than previously. A small ash emission occurred in April, May, July 2016, accompanying slight ash fall near the summit.
After Kunii(1950), the fumarolic activities existed in about 1894,1917, and 1918. A new fumarole was generated in 1927, but there were no reports of fumarolic activities after 1927, until the 1949 eruption occurred.
Japan Meteorological Agency observes or monitors the volcano activities or eruptions and publishes the data of volcanic activities as bulletins since Meiji era. Historically, such as Syowa era, disclosure or publications of them were not sufficient.
Niigata Local Meteorological Office has old observation data or documents on Niigata-Yakeyama. These data include the reports conducted by Kami-Hayakawa village in 1930s, and the investigation reports of the eruption that occurred in 1949. According to the documents, local inhabitants at about 10km from the summit crater heard the sounds of plume ejection, the sounds were like a jet engine or an automobile’s engine. The inhabitants also sensed the smell of volcanic gas in 1932. The villager or climbers found a hot geyser near the summit in July 1932. Local inhabitants saw ‘White Line’ on the slopes of Niigata-Yakeyama, actually that was a hot water flow. The same phenomenon occurred in the 1949 eruption, the 1974 eruption and in July 2016.
We re-inspected the documents of the eruption occurred in February 1949, and we estimated the amount of ash fall based on the data of ash fall depth. We compared those two eruptions, the 1949 eruption and the 1974 eruption, estimated which eruption was larger or more explosive.
In the 1949 eruption, an explosive sound or air shock were felt by the inhabitants at 16km from the summit crater. By contrast, in the 1974 eruption, an explosive sound was felt at 4 to 6km from the summit crater.
The 1949 crater was located at the east-side slope of the mountain, the 1974 crater was located at the west-side slope of the mountain, therefore the difference of crater location might cause the difference of explosive sound propagation.
The depth of ash fall of the 1949 eruption were about 30 millimeters at SEKI hot spring, TSUBAME hot spring, 21 millimeters along JR Shin-etsu Line, and 11 millimeters at Shinano-Daira station.
We estimated the amount of ash fall of the 1949 eruption, the weight of the total ash fall was at least about 2.0×10^6 tons. After Chihara(1975), the total amount of ash that was ejected of the 1974 eruption was 6.5×10^5 tons. We consider that the amount of ash fall of the 1949 eruption will be as same as that of 1974 eruption.
Seismic activity remains above background levels. According to GNSS measurements, the dilatation of the baseline that traverses the summit has declined since summer of 2016. We need to monitor volcanic activities continuously.

Keywords: Niigata-Yakeyama, 1949 eruption

High-frequency tremor with frequency transition at Mt. Asama, Japan

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There are few studies on volcanic tremor in a higher frequency range than 10 Hz. As an example, Hotovec et al. (2013) reported volcanic tremor with frequency transition from low to high (> 20 Hz) frequency ranges during eruption of Mt. Redoubt in 2009. In this study, we report high-frequency volcanic tremor at Mt. Asama with low-to-high frequency transition in a range of 20~30 Hz, on the basis of V-net data provided by NIED. We find the tremor 161 times at Takamine station and 36 times at Onioshidashi station during a period from January 1, 2011, to July 15, 2016. Function fitting on the frequency transition in spectrograms of vertical motion reveals that a logarithm form is the best. We investigate temporal distribution of the tremor occurrences and find that the tremor frequently occurred in the morning from November to April. This point implies a possible relation between the tremor occurrences and snow coverage on Mt. Asama.

Keywords: Volcanic tremor, High-frequency tremor, Mt. Asama, Snow coverage

Relation between long-period seismic signals and SO_2 emission at Asama volcano from October 2003 to January 2017

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Vulcanian eruptions had started on September 1st 2004, lasting until December 2004 at Mt. Asama. After that, several small and minor eruptions occurred in August 2008, from February to May 2009, and in June 2015. We compile long-period seismic data and SO_2 data from October 2003 to January 2017, and consider the relation between long-period seismic signals and volcanic gas emission. We categorize long-period seismic signals into three group; the first category is a very long-period pulse (VLP) excited by a sudden gas emission from northen part of the conduite [Takeo et al., 2016]. The second category is a long-period rebound waveform (LP earthquake), and the third category is long-period tremor characterized by pointed tips and sawtooth waveform. We propose a mathematical model succeeding in simulating the oscillations resembling with these second and third categories signals. Before June 2004, VLP activity was synchronized with the seismicity, but it had gradually decreased toward the eruption in spite of increment of the seismicity. At this turning point, LP earthquakes and nonlinear tremors occurred in cluster. Based on the mathematical model, LP earthquake and the nonlinear tremor could be actualized by a blockage of the conduit, resulting the decline of VLP activity due to shielding of gas emission and the increment of seismicity due to stress accumulation in and around the conduit [Takeo et al., 2016]. The minor eruptions in 2008 and 2015 were preceded by rapid activation of VLP activity and/or increment of SO_2 emission, and large VLPs preceded these minor eruptions by two to four minutes. Based on the VLP activity and SO_2 emission data, the minor eruptions in 2008 and 2015 were interpreted as large-scale gas emission events. SO_2 emissions had been kept in high level from November 2008 to February 2009 in spite of low VLP activity, but this relation had turned over from April to August 2009. After the 2015 eruption, SO_2 emission level often had been kept more than 1000 ton/day by the end of November 2015. After that, low SO_2 emission had been continued until December 2016 in spite of relative high level of VLP activity compared with that before the 2015 minor eruption. In this period, VLP activity seems to increase gradually, followed by a rapid increment of SO_2 emission in January 2017. The variability of correlation between SO_2 emission and VLP activity suggests an existence of multi outgassing pathways in the shallow part of the conduit.

Keywords: Asama volcano, Long-period earthquake, Volcanic gas

Mechanism of Stromoblian eruption at Aso volcano in terms of a model of slug ascending and bursting

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At Aso volcano, frequent Strombolian eruptions occurred in late April 2015, at a rate of 20-30 events every hour. Though Strombolian eruptions have been observed since 1930s at Aso volcano, the mechanism of generation of seismo-acoustic signals accompanying Strombolian eruption and the physical model of the eruptive process have not yet been revealed. In this study, we estimated the process of Strombolian eruption using the records of seismo-acoustic sensors deployed around the crater. Each eruptions was accompanied with characteristic signals of low- and high-frequency seismic waves and of infrasound waves. Dominant period of low-frequency seismic signal is 12 s, which is shorter than that of long-period tremor (15 s; Kaneshima et al., 1996). However, particle motion of this signal indicates similar source region as that of the tremor, 1-2 km depth beneath the crater. At the depth a crack-like conduit whose upper end connects to a much narrow path has been identified (Yamamoto et al., 1999; Yamamoto et al., 2008). At the conjunction portion at the roof of this crack, a slug can be made by a foam collapse (Jaupart & Vergniolle, 1988) and migrates upward to the crater. Mechanisms of very-long-period and long-period seismic signals accompanying Strombolian eruptions are considered as an association with a motion of a slug inside the magma conduit, especially structural discontinuous area (e.g. Aster et al., 2003). Based on this idea, we assume that low-frequency seismic signal observed at Aso volcano can be attributed to resonance of the crack when a slug enters the narrow conduit from the crack. Considering a result of explosion depth estimation, 200 m beneath the crater floor, inferred from time difference of seismo-acoustic signals, ascending speed of the slug is estimated as ~40 m/s. This value agrees well with the estimate at Stromboli volcano, 10-70 m/s (Harris & Ripepe, 2007). The dominant frequency of infrasound signal at the eruption is ~0.5 Hz. This band of air-pressure perturbations is also observed when no eruptions occur, but its amplitude is one order smaller than that at eruption. This means that the 0.5 Hz signal may be defined by the length of the conduit above the magma-air interface where explosions occur. This concept seems to be reasonable from a result of laboratory experiments modeling a bubble bursting (Kobayashi et al., 2010) in which a frequency of excited airwave at the bursting is the same as that of fundamental mode of the air column resonance above the interface. Here, assuming that a depth of magma surface (explosion depth) and the air sound velocity inside the conduit above the magma surface are 200 m and 400 m/s respectively, the frequency of the fundamental mode of air column resonance (one side open and the other side closed) can be calculated as ~0.5 Hz. This is precisely the same value of our observed frequency. Based on these facts, we suppose that release of internal pressure of the slug starts at a slug bursting at the magma surface, and forces amplitude of the air column resonance to increase. At the Strombolian eruption at Aso, we could also observe high frequency infrasound signal (> 10 Hz; 4-s duration). Though this signal is superimposed on the 0.5 Hz signal, it is clearly delayed ~0.3 s from the arrival of 0.5 Hz band. This high-frequency signal is probably related to continuous strong gas escaping that can break magma membrane surrounding the slug into small fragments. However, an exact reason why it takes 0.3-s delay from the start of slug rupturing is not yet clear.

Keywords: Aso volcano, Strombolian eruption

A study of the temporal change in oscillatory characteristics of Long-period tremor at Aso Volcano, Japan

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Low-frequency earthquakes and long-period events observed at active volcanoes are considered to be generated by the motion of volcanic fluid like magma and volcanic gases, and the elucidation of these signals and their temporal change are one of the critical keys to understand the dynamics of the volcanic system. At Aso volcano, various kinds of volcanic signals with broad frequency contents have been observed since the pioneering work by Sassa in 1930s. One of these signals is long-period tremor (LPT) with a dominant period of around 15 s, which are intermittently emitted from the volcano regardless of the surface activity. The characteristics of the LPTs are fairly short duration of only a few cycles and multiple spectral peaks at 15 s, 7 s, and so on. Our observations using broadband seismometers so far have revealed that LPTs are a kind of resonance oscillation of a crack-like conduit beneath the crater. Because the resonance characteristics of a fluid-filled crack are strongly controlled by the physical properties of the fluid inside the conduit and the geometry of the conduit, in this study, we analyze the temporal variation of oscillatory characteristics of Long-period tremor from 1994 to the present.

In this study, we first examine the temporal variation of dominant periods of LPTs (fundamental mode of around 15 s and first overtone of around 7 s) using the continuous data recorded at broadband seismic stations close to the active crater. The result shows clear temporal change in the dominant periods of LPTs in 2003-2005 and 2014-2015. These two time periods corresponds to the periods in which small phreatic and phereatic/magmatic-hydrothermal eruptions occurred. As to the temporal variation in 2003-2005, as already reported by Ikeda (2005) and Yamamoto (2013), the periods of the fundamental mode and the first overtone show correlated temporal change, and it can be interpreted as compositional and/or thermal change of hydrothermal fluids. On the other hand, in 2014-2015, the period of first overtone is almost constant at around 8 s, while that of the fundamental mode shows relatively large temporal fluctuations between 16 s and 12 s. Such a trend is rather difficult to explain, if we consider the resonance oscillation of a flat fluid-filled crack.

In this study, we therefore examine the oscillatory characteristics of a fluid-filled crack having linearly varying thickness. As a result, it becomes clear that the dispersion of the boundary wave along the fluid-filled crack becomes weaker and thus the ratio between resonance periods of the fundamental mode and the first overtone becomes smaller than the case of a flat crack having constant thickness. This behavior can be understood by considering that the effective thickness of the crack depends on the wavelength of each resonant mode. Based on these results, the different temporal variation of dominant periods of the two resonant modes can be interpreted by depth-dependent thickness of the crack-like conduit which caused by pressurization and/or intrusion of magma at deeper portion of the conduit. Our result suggests that the long-term trend in the state of volcanic fluid systems beneath active volcanoes may be monitored by seismological means.

Keywords: Volcanic earthquake, Hydrothermal system, Boundary wave

Long period pulse preceding the explosive eruption of Aso volcano, October, 2016

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At 01:40, October 8, 2016, an explosive eruption occurred at the Nakadake first crater of Aso volcano. Type of the eruption is regarded as phreatomagmatic eruption because glassy particles are included in the ejecta (JMA,2016). Two long period pulses(LPP) were observed 6 minutes and 2 minutes before the eruption, which we called LPP1, LPP2, respectively.
In this work, we analyzed the broadband seismograms in order to unveil the source mechanism of the LPPs since it is thought that the mechanism contains the information of the preparatory process of the explosive eruption.
We used the broadband seismic data at 8 stations around the Nakadake first crater. The distances from the crater to each station are 0.3~2.3km.
Based on the particle motions at each station, we estimated the source location of LPPs by waveform semblance method (Kawakatsu et al. 2000). It was estimated that the source of LPP1 is located at 270m south-west of the crater (32.88237N, 131.08416E), 0m above sea level, and the source of LPP2 is located at 300m south-southwest of the crater (32.88237N, 131.08416E), 120m above sea level. They are about 100m apart from the LPP source location estimated in Kawakatsu et al.(2000). In addition, compared with the location of the crack-like conduit under the crater(Yamamoto et al. 1999), LPP sources are in or close to the crack. Moreover, we calculated RMS amplitude of 10~30s band-pass filtered vertical seismogram. As a result, the amplitude distribution is very similar to long period tremor(LPT) that was observed in Yamamoto et al.(1999). Thus, it is inferred that same conduit behavior, a resonance of the crack-like conduit, can be a source model of LPP. Furthermore, our result shows that the source moved upward between two events, however, it is under investigation whether this move is significant or not.
Then, we calculated Fourier spectrum of LPPs with time width of 150 seconds. Spectrum peaks of LPP1 are 12~20s(unclear), 7.5s, 5s, and those of LPP2 are 17s, 10s, 6s. Period of LPP2 is longer than LPP1. It is thought that LPP period depends on the conduit length, or sound velocity of the fluid in the conduit because LPP is interpreted as resonance of the conduit(Kawakatsu et al. 2000). Thus, the conduit condition likely changed between two events, which occurred within 4 minutes just 2 minutes before the explosion.

Keywords: Aso volcano, explosive eruption, long period pulse

Chemical composition of minerals and melt inclusions in Kusasenrigahama pumices from Aso volcano, Kyushu, Japan -Comparison with Aso-4-

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In this study, we analyzed Kusasenrigahama pumice to compare with Aso-4 volcanic product about whole rock chemical composition, chemical composition of minerals and melt inclusion, and water concentration in melt inclusion. Kusasenrigahama pumice was erupted from Kusasenrigahama pumice cone about thirty thousand years ago, which is in the west of Aso central cones. We collected pumices from four volcanic sand layers in the outcrops at the west –southwest of Kusasenrigahama pumice cone. The four layers were distinguished by pumice size and volcanic sand’ s color: A, B, C, and D, in ascending order. Kusasenrigahama pumice contains plagioclase, orthopyroxene, clinopyroxene, and opaque as minerals.

Results of analysis show that mineral composition of Kusasenrigahama pumice is homogeneous, scale of volcanic activity depends on water concentration, and magma chamber under the Kusasenrigahama pumice cone is lower water concentration and higher temperature, compared with Aso-4.

(a) Uppermost and lowermost layer of Kusasenrigahama pumice shows nearly the same chemical composition of constituent minerals (plagioclase; An# = 64 ~68, clinopyroxene; Mg# = 75 ~ 77, orthopyroxene; Mg# = 72 ~ 74). Clinopyroxene and orthopyroxene is almost the same composition between Kusasenrigahama pumice and Aso-4. On the other hand, plagioclase composition of Kusasenrigahama pumice is different with that of Aso-4.

(b) Water concentration in MI of lowermost layer (A) is higher than that of uppermost layer (D). Compared with Aso-4, MI of Kusasenrigahama pumice contains less water.

(c) Clinopyroxene and liquid thermobarometers shows temperature and pressure, 897 ±45 ℃, 1.8 kbar respectively. When this pressure is applied, plagioclase and liquid thermometer shows temperature, 888 ±37 ℃. These temperature is higher than temperature of Aso-4 (810 ~ 850 ℃).

Keywords: Aso volcano, Melt inclusion, Kusasenrigahama pumice

Volatile content of magmas of the 2014, 1989, and 1979 eruptions of Naka-dake, Aso volcano based on melt inclusion analyses.

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Volatile content of magma is one of important controlling factors for magma ascent and volcanic eruption. Melt-inclusion analysis is a powerful method for estimating volatile content of melt in magma before eruption. At Naka-dake, Aso volcano, volcanic activity increased September 2013, and minor eruptions occurred January 2014. Since then, eruptions had intermittently occurred up to October 2016, together with intense volcanic gas emission. In this study, we carried out petrological observation and chemical analyses of melt inclusions of the scoria of the 2014, 1989 and 1979 eruptions of Naka-dake to know the eruption and degassing processes.
Whole-rock composition of the scoria was determined by a wave-dispersive X-ray fluorescence analysis (XRF). Observation of the cross sections, chemical analyses of the minerals, determination of major elements and sulfur contents of melt inclusions and groundmass were carried out by electron probe micro analyzer (EPMA). Water and CO_2 contents of the melt inclusions and matrix glass were determined by secondary ion mass spectrometry (SIMS). Analytical errors of the volatile analyses were ±0.2 wt.% for H_2O, ±0.0028 wt.% for CO_2, ±0.007 wt.% for S (Saito et al., 2010).
Five scoria of the 26-27 November 2014 eruptions have andesite composition (SiO_2 =54 wt.% and K_2O=2.0 wt.%) and are identical to those of scoria of the November 1979 eruptions (Ono and Watanabe, 1985). The scoria contained 22-31 vol % plagioclase phenocrysts, 5-13 vol % clinopyroxene phenocrysts, a few vol % of olivine and FeTi-oxide phenocrysts. The plagioclase phenocrysts have core of An_{62-91} and rim of An_{60-79}. The clinopyroxene phenocrysts have core of $Wo_{36-41}En_{43-47}Fs_{15-20}$ and rim of $Wo_{36-40}En_{42-46}Fs_{17-19}$. The olivine phenocrysts have core of Fo_{65-68} and rim of Fo_{59-68}. Two-pyroxene thermometry (Lindsley, 1983) applied to an orthopyroxene inclusion contained by a clinopyroxene phenocryst gave magma temperature of 1113±51ºC. Melt inclusions in plagioclases, clinopyroxenes and olivines have andesite composition (SiO_2=58-62 wt.%, K_2O=3.1-4.7 wt.%), that is similar to chemical composition of the groundmass. The melt inclusions have volatile content of 0.6-0.8 wt.% H_2O, 0.003-0.017wt.% CO_2 and 0.008-0.036 wt.% S. The variation in CO_2 and S contents of the melt inclusions is not related to the K_2O content, suggesting magma degassing with pressure decrease. Gas saturation pressure estimated from the H_2O and CO_2 contents and solubility model (Papale et al., 2006) is 22-78 MPa, corresponding to 1-3km depths. Combining the melt-inclusion analysis with observation of volcanic gas, we can estimate degassed-magma volume. The amount of degassed magma (1-3 km^3) was estimated, based on the sulfur contents of the melt inclusions and SO_2 flux during a period of January 2014 to December 2016 (1000-3000 t/d; JMA, 2016), assuming that only SO_2 existing as sulfur component in the volcanic gas and magma density of 2700 kg/m^3.
Melt inclusions in plagioclases, clinopyroxenes and olivines from the 1979 and 1989 eruptions have andesite composition (SiO_2=57-62 wt.% and K_2O=2.3-3.8 wt.% for 1979 eruptions, SiO_2=57-63 wt.% and K_2O=3.2-5.4wt.% for 1989 eruptions). The melt inclusions of the 1979 eruptions have volatile content of 0.3-1.6 wt.% H_2O, 0.007-0.034wt.% CO_2 and 0.010-0.035wt.% S. The melt inclusions of the 1989 eruptions have 0.3-0.6 wt.% H_2O, 0.003-0.009wt.% CO_2 and 0.008-0.031wt.% S. Major elements and volatile contents of melt inclusions of the 2014 eruptions are similar to those of the 1979 and 1989 eruptions. The similarity of chemical composition of whole-rocks and melt inclusions among these eruptions suggest petrologic characteristics and volatile content of the magma in the magma chamber had not changed from 1979 to 2014.

Keywords: Aso volcano, Naka-dake, magma, melt inclusion, volatile, degassing

The injection of high-sulfur basaltic magma into shallower reservoir beneath Aso

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We analyzed the major elements of bulk rock, melt inclusion (MI) of minerals and host minerals and volatiles (H_2O, Cl, S) of MI of Holocene volcanic products from the northwestern part of Aso central cones to obtain the information of magma reservoir.
In this study, we used scoria samples of Ojodake and Kamikomezuka, which erupted in Holocene. Bulk rock composition of samples were determined by X-ray fluorescence (XRF) at Kitakyushu Museum of Natural History and Human History. Sample preparation techniques and analytical procedures are based on those of Mori and Mashima (2005). Major elements and volatiles (S, Cl) of MIs, host minerals and glasses were determined by SEM-EDS at Kumamoto university and EPMA at Earthquake Research Institute, University of Tokyo. Water concentrations in MIs were measured by Fourier transform infrared (FT-IR) micro-reflectance spectroscopy at ERI, university of Tokyo (Yasuda, 2011, 2014).
MIs of the phenocrysts shows two compositionally different types. One is mafic (SiO_2 46.7-57.5 wt. %) and high-S (<4000 ppm), and the other is felsic (SiO_2 52.3-59.8 wt. %) and low-S (<1000 ppm). Mafic group is hosted in olivine (Ol), felsic group are hosted in plagioclase (Pl), clinopyroxene (Cpx) and orthopyroxne (Opx). Matrix grass has intermediary composition of them. Volatiles of matrix glass were almost degassed. The S contents of Ol hosted MI tend to decrease with decreasing hosted-Ol Mg#. About felsic group, measured H_2O contents in melt inclusions from Ojodake are highest (<3 wt. %); Kamikomezuka inclusions have lower H_2O values (<1 wt. %). Those of mafic group were mostly below detection (Max 0.8 wt. %).
Some phenocrysts of Pl and Cpx exhibits reverse zoning at the rim. Pl phenocrysts were divided into two groups, an Ab-rich core (An 60-65) and an An-rich core (An 85-87). Opx phenocrysts typically have a reaction rim of Cpx and Ol.
High volatile/K_2O ratios of MI hosted Ol indicates that it has high volatile contents initially. High-S content mafic magma was found by melt inclusion studies beneath the frontal volcanoes in central and northeastern Japan (Yamaguchi et al., 2003; Yamaguchi, 2010). It has become clear that volatiles in arc magma are enriched by subduction (Wallace, 2005; Zellmer et al., 2015). In general, the high S contents of basaltic melt require oxygen fugacity (fO_2) greater than FMQ+1 (Wallace, 2005; Jugo et al., 2005; Jugo, 2010). And there is some correlation of S content in the melt with Fe content, fO_2 and temperature (Wallace & Carmichael, 1992). The compositional gap of S contents between mafic and felsic group may reflects the degree of differentiation.
In considering the low-SiO_2, high-Mg# and volatiles in MIs and disequilibrium texture of felsic group phenocrysts, it is concluded that mafic group derived from deep-reservoir. These observations are explained by the injection of high-S basaltic magma into shallower reservoir.

Keywords: Aso, EPMA, FT-IR, melt inclusion, sulfur, water content

Estimation of subsurface velocity structure beneath Kirishima volcanoes inferred from ambient seismic noise tomography

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Shinmoe-dake, one of Kirishima volcanoes, experienced magmatic eruptions in 2011. The analysis of ground deformation shows that the pressure source locates 5 km to the northwest of the Shinmoe-dake summit at a depth of 8 km, which implies the existence of a magma reservoir. We are trying to resolve the better image by a seismic exploration technique toward ensuring its existence and deriving precise crustal structure.
The technique we employed is the seismic wave interferometry, which extract the seismic wave propagation between two seismic stations by taking a cross correlation of random wavefields, such as the ambient seismic noise or the seismic coda wave, recorded at two stations. The cross correlations of random wavefields recorded at two receivers can be represented as if the source is at one receiver and the recorder is at the other. This technique is suitable for exploring local structure since the extracted wave is sensitive to the internal structure between two stations.
We inferred the crustal phase velocity anomaly using three-component records of the ambient seismic noise recorded by seismic array between April 2011 and December 2013. Rayleigh and Love waves are extracted by taking cross correlations (Rayleigh waves from Z-Z and R-R components of cross correlation functions, and Love waves from T-T component). We derived reference dispersion curves of Rayleigh and Love waves, respectively, using all pairs of stations, then measured a phase velocity anomaly against the reference for each pair in four frequency ranges (from 0.1 to 0.2 Hz, from 0.2 to 0.4 Hz, from 0.3 to 0.6 Hz and from 0.4 to 0.8 Hz) for Rayleigh wave and in two frequency ranges (from 0.3 to 0.6 Hz and from 0.4 to 0.8 Hz) for Love wave.
The inferred Rayleigh wave phase velocity structure shows that the inside of Kirishima volcanic region and nearby region have the characteristics of low velocity against the outside for all frequency ranges. In particular, the Rayleigh wave phase velocity structure in a frequency range from 0.1 to 0.2 Hz (corresponding to around 5-10 km depth) is characterized by two remarkable low velocity regions: one lies at almost same location of the pressure source of the ground deformation, and the other is located beneath the region from Shinmoe-dake to Ohata-ike. Similar characteristics are found from 0.2 to 0.4 Hz (around 3km depth) and from 0.3 to 0.6 Hz (around 2 km depth) for Rayleigh wave. They are also detected in a frequency range from 0.3 to 0.6 Hz for Love wave. The Love and Rayleigh wave velocity structures from 0.4 to 0.8Hz (around 1km depth) show low velocity characteristics right beneath the entire volcanic region.

Keywords: Kirishima volcanoes, surface wave velocity structure, ambient seismic noise

One-dimensional resistivity structure and the relocated hypocenter distribution of Iwo-yama, Kirishima Volcanoes

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Iwo-yama is the youngest volcano in the Kirishima volcanic group. Around Iwo-yama and Karakuni-dake, shallow (depth < 2km) tectonic earthquakes have increased since December 2013, and volcanic tremors have occasionally occurred since July 2015 (Japan Meteorological Agency, volcanic activity commentary document). Furthermore, the fumarolic gases appeared in December 2015 for the first time in 12 years. The leveling survey detected the ground uplift during June to December 2015, and its pressure source was estimated at a depth of 700 m, 150 m east of the crater (Matsushima et al.,2015). Therefore, it is reasonable to be concerned about the occurrence of hydrothermal eruptions.
In order to investigate the mechanism of these volcanic activities and possibility of future eruptions, we conducted broadband (0.005 to 3000s) magnetotelluric (MT) measurements around the Iwo-yama in April 2016. We recorded two components of electric fields at 20 observation sites and five components of electric and magnetic fields at 7 observation sites. One-dimensional inversion revealed that the shallow earthquakes occur beneath a shallow electric conductive layer, which is interpreted as a hydrothermal altered clay dominant zone. The pressure source by the leveling survey corresponds to the bottom of the conductive layer. These spatial relationships suggest that the supply of high temperature fluids has increased beneath Iwo-yama, and causes the increase in pore pressure beneath clay layer, resulting in the increase of earthquakes and ground inflation. In this presentation, we will further estimate the precise depth of earthquakes, and will investigate its relation to the shallow conductive layer.

Vertical ground deformation of Ioyama, Kirishima volcanoes measured by precise leveling survey (during Mar. 2012 - Nov. 2016)

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Ioyama is an active volcano located in Ebino kogen volcanic area, Kirishima Volcanoes, southern Kyusyu, is activated from December 2015. We conducted the precise leveling survey in the Ebinokogen volcanic are from March 2012 to November 2016. The purpose of the survey is to reveal the vertical deformation and pressure source. We measured in December 2015, February, March, June, November 2016. Inflation of the Ioyama was detected from we initiated this observation to March 2016. Subsequently, the ground subsidence from around June 2016. However, uplift is detected around the Ioyama again in November 2016.

From the surveyed leveling data in November 2016, the vertical displacements indicate the ground uplift at all bench marks. In this study, the reference bench mark is BM1120 at the western flank of Ioyama. The amount of maximum uplift is about 17.2 mm near the summit referred to BM1120 in November 2016. We estimated pressure source models based on the vertical deformation. We supposed the presence of an inflation spherical source as Mogi' s model, the depth has been inferred about 700 m. The lower limit of low resistivity layer assumed to be the clay layter is estimated in this depth (Aizawa et al., 2013). Accordingly, the inflation source by using precise leveling survey is located under the impermeable clay layer. In addition, the increase of pressure source volume since June 2015 is detected 4.8×10^4 m^3 in November 2016.

Keywords: Ioyama, precise leveling survey, vertical deformation

Distribution and occurrence of the pyroclastic flow deposit of the 2011 eruption of Shinmoedake, Kirishima volcano group, Southern Kyushu, Japan

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We investigated occurrence of the pyroclastic flow deposit of the 2011 Shinmoedake eruption about 5 years later. During a subplinian eruption, very small pyroclastic flows descended down on the south-western slope up to 800 m long, with 30 m wide. The volume of the deposit is estimated to be about 20,000 m^3. No splintered stumps were found on the course of the flow, so it suggests that the speed of the flow was slow. The pyroclastic flow was estimated to be generated by a small-scale partial collapse of the subplinian eruption column.

Keywords: Kirishima volcano group, Shinmoedake, 2011 eruption, pyroclastic flow, sub-plinian

Infrasonic activity of Sakurajima volcano in 2015, inferred from an infrasound array analysis.

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In Sakurajima volcano, explosive eruptions have occurred frequently at around 1000 times at a year since 2009, and continuous geological investigations, such as infrasound, seismicity, tilt, and Global Navigation Satellite System (GNSS) have been used to monitor the volcanic activities (Iguchi et al., 2013). On August 15, 2015, the magma intrusion event different from usual state occurred. It is reported that the frequency of the explosion decreased across that period. In this study, we report the outline of the infrasound activity of Sakurajima from January to December 2015 recorded by an infrasound array.

In October 2014, we installed the infrasound array (TKT) in the Kagoshima University research forest at Takatoge-Kogen (11 km southeast of the Sakurajima Showa crater, altitude of 540 m). Four stations of array were installed; three stations were placed at each vertex of the triangle whose aperture of 200 m, and the other at the center. Three of them are installed with sensor (differential pressure gauge) and digitizer, power is supplied by the solar panel. Power of the other station is supplied by commercial power and we also installed the sensor, digitizer and data aggregation-transmission system. The data were recorded at a sampling rate of 50 Hz and transmitted by fiber optic cables. The central station and the other stations are connected by fiber optic cables passed through a protective tube and buried in the 20-30 cm underground to avoid the influence of thunder and animals. However, in the vicinity of a rough ground situation covered with thick leaves, cable exposure due to rain fall accompanying the outflow of the ground surface cannot be avoided and it became impossible to communicate in about one and a half years after installation. Although there are data missing due to power of PC failure intermittently, data is acquired continuously from January to December 2015. In this time, we analyzed the date in that period.

Median filter processing and trend removal were performed on the obtained data, and then a 0.3-5 Hz band pass filter was applied. First, based on the Sakurajima eruption record table by the Japan Meteorological Agency (JMA), records in TKT 15 minutes before and after the JMA’ s explosion record time was cut out, and a semblance analysis was continuously performed while varying the time by 5 s at an analysis length of 10 s to event detection and estimate the direction of infrasound arrival. After that, with respect to each station, a cross correlation function assuming that the delay time when signal comes from the Showa crater is calculated every 1 s, a moving average of 5 min is applied, and from January to December 2015 to estimate the infrasound activity of Sakurajima.

636 explosions occurred during the TKT’ s operation among the 737 explosion records in 2015 by JMA, and all infrasound data were recorded in TKT. Of the explosion recorded in TKT, even for the one with the smallest infrasound amplitude in Seto (1.3 Pa), we confirmed that for the all signals predominantly arrived from Sakurajima direction (300°N). In the case of a large amplitude explosion, it was also confirmed that reflected waves from the topography around TKT arrived, as pointed out by Yokoo et al., (2014). The reflection wave arrived mainly from 180°N to 130°N. These are reflected waves from Mt. Yokodake and Mt. Takakuma , sounth and southeast to TKT station. In addition, the reflected waves from the 80°N direction are relatively weak, and these are considered to be due to the direction of the Kushira river, the altitude is lower than around.

Next, we analyzed the energy of infrasound continuously coming from Sakurajima, using the cross-correlation function. In order to distinguish the increase in the local noise, we also calculated the power of infrasound simultaneously arriving from the direction of the Kushira River (80°N) as a reference. As a result, also between the reported explosion-eruption, it is confirmed that week infrasound activities occur continuously or intermittently. In the future, we will clarify what kind of surface activity corresponds when weak infrasound recorded at TKT, in combination with infrasound data and movies in the vicinity of Showa crater. Also, we would like to consider how much it affects the eruption cycle and scale.

Keywords: Volcanic erupiton, Sakurajima Showa Crater, Infrasound array analysis

Time variations between shock wave and a subsequent formation of bright cloud at Vulcanian eruptions of Showa crater, Sakurajima volcano, Japan

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To investigate mechanism of Vulcanian eruption, we analyzed eruption movies (30 frame/s) of Showa crater, Sakurajima volcano, Japan. 88 eruptions during December 2011 to May 2015, which accompanied variable infrasound wave, were selected for an analysis. First, we investigated the relationship between an intensity of infrasound and a speed of volcanic plume at the crater. Maximum amplitude of infrasound data observed at Seto and Arimura stations (JMA) shows positive correlations with the ejection speeds of volcanic plume. This result thought to be consistent with preceding vulcanian eruption models (Turcotte et al., 1990; Woods, 1995; Alatorre-Ibargüengoitia et al., 2010) which shows ejection speeds increase if overpressure in the conduit increase. Second, we investigated the time lag between an onset of visible shock wave and a subsequent formation of bright (white) cloud close to the crater. The obtained time lag varies from 0.2 to 1.1 s with maximum frequency 0.6s, and may be related with the variation of size and/or the location of "gas pocket" (e.g., Ishihara, 1985; Iguchi et al., 2008) formed under the crater just before the explosion at Sakurajima.

Real-time analyses of continuous relative gravity data collected at Sakurajima Volcano

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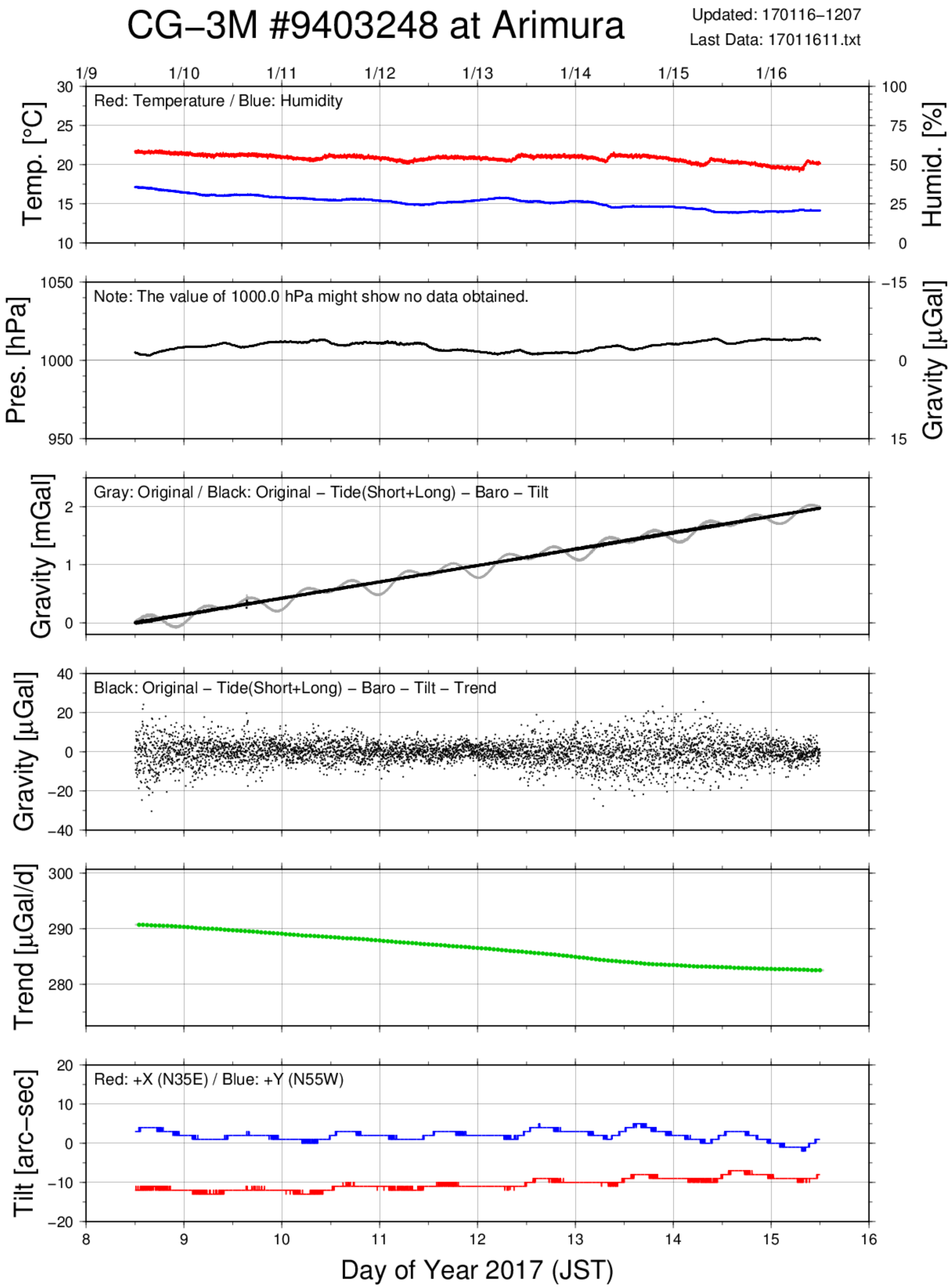
Continuous gravity observation is one of the most powerful methods to monitor mass redistributions in volcanoes. In Japanese volcanoes, absolute gravimeters have detected gravity changes of less than 10 microGal originating from volcanism, with those time period of more than a few days (e.g., Kazama et al., JGR, 2015). However, absolute gravimetry cannot precisely detect short-period (< one day) gravity changes due to the low signal-to-noise ratio in the high frequency domain. On the other hand, broadband volcanic phenomena have been monitored by other geodetic observations at many active volcanoes (e.g., Iguchi et al., JVGR, 2008). If the short-period volcanic gravity signals can be detected by continuous gravity observations other than absolute gravimerty, volcanic phenomena will be minutely discussed in terms of mass redistributions.

Kazama et al. (Kazan, 2016) thus installed a CG-3M relative gravimeter at Arimura in the southern part of Sakurajima Volcano, and started collecting continuous gravity data at one-minute interval. They succeeded in detecting a rapid gravity decrease of -5.86 microGal during the rapid inflation event on 15 August 2015; this gravity change is smaller than the typical observation error of relative gravimeters (~10 microGal), but the high-frequency measurements of relative gravity contributed to the detection of the small gravity change in the case of Sakurajima Volcano. They also pointed out that the gravity change was consistent with one of the dike intrusion models provided by Geospatial Information Authority of Japan (2015) if the density value of 0.97 +/- 0.37 g/cm3 was assumed, which implies the drastic foaming of the intruded magma.

We utilized their method to construct the real-time analysis system of continuous relative gravity data collected at Sakurajima Volcano. The following procedures are automatically executed every hour in this system. (1) Continuous data of relative gravity and air pressure are uploaded from logging laptops to a server. (2) The gravity/pressure data is downloaded from the server to a computer installed in Kyoto University. (3) Three effects are corrected from the raw gravity data: tidal gravity change, gravity change due to air pressure change, and artificial gravity change due to instrumental tilts. (4) Instrumental drift is removed, by fitting a linear function to the corrected gravity data of the past seven days. (5) Graphs of the collected/analyzed data are drawn and uploaded to a web server.

We show one of the graphs drawn by this system at noon on 16 January 2017. This graph displays the seven-day variations in air pressure, raw gravity, corrected gravity, drift rate, and instrumental tilts. If significant mass redistributions occurred associated with volcanism, rapid time variations could be included in the panels of corrected gravity and drift rate, and/or instrumental tilts might change due to volcanic inflations, as detected on 15 August 2015 (Kazama et al., Kazan, 2016). We are going to maintain this analysis system in order to monitor mass redistributions associated with volcanism in Sakurajima Volcano instantaneously.

Keywords: Sakurajima Volcano, volcanism, gravity change, relative gravimeter, mass distribution



CG–3M #9403248 at Arimura
Updated: 170116–1207
Last Data: 17011611.txt
1/9
1/10
1/11
1/12
1/13
1/14
1/15
1/16
Red: Temperature / Blue: Humidity
Temp. [°C]
Humid. [%]
Note: The value of 1000.0 hPa might show no data obtained.
Pres. [hPa]
Gravity [µGal]
Gray: Original / Black: Original – Tide(Short+Long) – Baro – Tilt
Gravity [mGal]
Black: Original – Tide(Short+Long) – Baro – Tilt – Trend
Gravity [µGal]
Trend [µGal/d]
Red: +X (N35E) / Blue: +Y (N55W)
Tilt [arc–sec]
Day of Year 2017 (JST)

Structural state of plagioclases within volcanic ash from Sakurajima volcano: Preliminary investigation of monitoring volcanic activity by constituent mineral

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Sakurajima volcano, one of the most active volcanoes in Japan, has seen an increase in the magnitude and frequency of activity over the past decade. This activity has been studied by many geophysicists, with most focusing on seismic waves and crustal movement that occurred nearby. Many geochemists have approached igneous activity from the viewpoint of whole-rock chemical analysis and mineral composition analysis of direct products, such as volcanic ash and lapilli, but few studies have applied crystallography in analysis. The goals of this study are to obtain basic data for understanding magmatism just under the Sakurajima volcano and to construct a new and efficient method for investigating and monitoring volcanic activity, focusing on the crystal structure of constituent minerals within the volcanic ash. Toward this second goal, the structural state of plagioclases within volcanic ash erupted from Sakurajima volcano was preliminarily investigated. Samples were collected for about 27 months starting in May 2013 at Higashi-Sakurajima Junior High School, which is located about 4 km southwest of Minami-dake crater. It is known that $\mathrm{B}(2\theta_{(1\text{-}11)} - 2\theta_{(\text{-}201)})$ versus $\Gamma(2\theta_{(131)} + 2\theta_{(220)} - 4\theta_{(1\text{-}31)})$ for plagioclases, as determined from X-ray powder diffraction data, distinguishes among structural states and gives a rough estimate of plagioclase composition. The B/Γ plot measured for the plagioclases in the volcanic ash suggests a gradual change in degree of order in the crystal structure during this period. Further results from long-term analysis of volcanic ash are expected to clarify aspects of the volcanic activity of Sakurajima volcano.

Keywords: Sakurajima, volcanic ash, plagioclase, X-ray powedr diffraction, structural state

Development of Unmanned Ash-fall Detection System, Part2

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We developed revised unmanned facility to detect pyroclastic fall deposit since the 2011 eruption of Kirishima Shinmoedake and Sakurajima volcanoes. Our goal is to develop a method to obtain the semi-real time information of pyroclastic fall phenomena to contribute eruption forecasting and to advance high precision reconstruction of the sequence of the past eruptions from their deposits. Our revised system is named "Futteru-kai (kai means ash in Japanese)" consists of ultrasonic distance probe, load cell, and network camera supplied by 12 volts battery with solar panel. Electric equipment are packed within waterproof vessel to protect sulfuric gas invasion. Testing was performed at Sakurajima Arimura from January 2015 to March 2016. Load cell shows large variance depending on temperature with negative correlation. Ultrasonic distance probe showed stable value slightly diminishing which suggests deposition of pyroclastic fall deposits on measuring surface. Minor outlying results several times larger than actual value or over-range were also observed. Two centimeters of diminishing distance between the probe and the surface is well coincided with actual measured distance. We are now preparing to dispatch next volcano where major ash fall eruption is expected.

Keywords: monitoring, eruption, ash fall, ultrasonic, Sakurajima

Pyroclastic flow deposit of the 2015 Kuchinoerabujima Volcano

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Explosive phreatomagmatic eruption on May 29, 2015 of Kuchinoerabujima Volcano produced pyroclastic density currents (PDC) in all directions from the summit crater of Shindake. The PDC reached to the coastal line ~2 km from the summit crater. The PDC is characterized with the distribution of thin deposit. The thick block and ash flow deposit distributed in a limited area within the vicinity of the crater. Nevertheless the thin deposit, most of the trees in the area of the PDC were broken and overturned, suggesting a strong flow with high velocity. No remarkable wildfire in the PDC area suggested that the temperature of the deposit was not reached the ignition temperature of the wood. However, the facts that all leafs on the trees within the peripheral PDC area were killed by the thermal damage and one person involved in the PDC got burn injury suggest that the temperature within the PDC was fatal.
We surveyed the distribution and sequence of the PDC deposit and thermal and mechanical damages by the PDC within the area of PDC. The thermal damage was remarkable in the upper part of the trees which were directly exposed to the PDC. The thermal damage on the trees were limited within the area of PDC. No thermal damage was recognized in the area where was covered by the ash fall from the PDC. The nylon items in the PDC deposit were partially melted. The thickness of the deposit at the end of the PDC area in Mukaehama was less than 5 cm. The deposit shows remarkable normal-grading from lapilli and very-coarse sand at the base to very-fine sand at the top. At the base of the deposit, lapilli ~1.5 cm in diameter were found. Many plant fragments in the deposit tell the strong flow which destroyed the forest along its pass. These observations indicate that the deposit was formed by a short and single-pulse PDC with high velocity. This is consistent with the visual observations by some monitoring cameras.

Keywords: volcano, eruption, pyroclastic flow , Kuchinoerabujima Volcano, phreatomagmatic eruption

Enhancement of volcanic observation system of JMA near the volcanic crater

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1. Introduction
Based on lessons learnt from the eruption of Ontake Volcano on 27 September 2016, the Coordinating Committee for Prediction of Volcanic Eruptions discussed enhanced monitoring systems for active volcanoes and proposed urgent recommendations on November 2014; a final report from the Committee was also published on 26 March 2015. Responding to these recommendations and report, Japan Meteorological Agency (JMA) decided to install various instruments near volcanic craters and increase the number of observation facilities to continuously monitor more volcanoes. Furthermore, JMA started to develop methods for earlier detection of precursory phenomena of phreatic eruption. In this report, we will show the outline of our efforts to enhance the monitoring systems and some observational results.

2. Enhancement of observation systems near volcanic craters
In general, intensities of preceding activities of phreatic eruptions are weak and appear only in the vicinity of the crater. In order to monitor and detect small precursors, JMA decided to install following instruments near the craters of 48 active volcanoes in Japan: (i) infrared and visible light cameras to monitor thermal activities and change of fumaroles, (ii) broad-band seismometers and tiltmeters to detect low-Frequency seismic signals caused by the movements of volcanic gas or hydrothermal activities. Since such instruments are installed in high places around craters, they are often exposed to severe weather conditions, such as strong winds, heavy snow and lightning. In order to keep stable operations, we took care of the robustness of the systems.

3. Development of methods for earlier detection of precursory signature of phreatic eruptions
Changes of volcanic gas composition and geomagnetic total intensity were often observed prior to past phreatic eruptions. JMA, therefore, decided to observe components of volcanic gas (4 volcanoes) and geomagnetic total intensities (6 volcanoes, including scheduled) near the craters of volcanoes and start to develop methods for earlier detection of precursory signature of phreatic eruptions. Since JMA does not have any experience to conduct continuous volcanic gas observations, we installed instruments with the cooperation of Meteorological Research Institute (MRI) and National Institute of Advanced Industrial Science and Technology (AIST).

4. Examples of observed data
We observed a volcanic tremor accompanied by a long-period seismic signal and small tilt change around Ontake Volcano on 27 September 2016. We also recorded the thermal image at the moment of the eruption of Aso Volcano on 8 October 2016. JMA is going to investigate techniques for accurate evaluation of volcanic activities by using data observed by these newly installed instruments. The observation data will become available for research institutes; it aims to encourage effective data utilizations and extensive developments in volcanological studies. It is expected that such developments will give positive feedback to JMA’s volcanic activity evaluation process.

Keywords: phreatic eruption, tiltmeter, broadband seismometer, infrared and visible light cameras

Ground Deformation around Domestic Active Volcanoes detected by D-InSAR of ALOS-2/PALSAR-2 (2014 -2016)

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Monitoring of volcanic activity by observing ground deformation is one of useful means to understand signs of eruption such as migration and accumulation of magma and volcanic fluids. Japan Meteorological Agency (JMA) monitors volcanic activity by tiltmeter, light wave distance measuring and GNSS around volcanoes. However, there are some problems only using these ground-based observation methods. Observable ground deformation is restricted to point information such as the tilt at the observation point and relative position between observation points. Also, it is difficult to install and maintain observation device due to bad transportation infrastructure at remote mountainous volcanoes, heavy snow and keep-out area by eruptions. It is important to grasp surface ground deformation around volcanoes using not only ground-based observation but also satellite data like SAR (Synthetic Aperture Rader).
PALSAR-2, an L-band SAR on ALOS-2, is useful to understand ground surface state, and its interferometric coherence is highly effective for the ground deformation observation. PALSAR-2 has higher efficiency than ALOS/PALSAR. It is short repeat observation cycle (14days) and has a high resolution sensor and can realize right-side and left-side observation. Therefore, we can use higher resolution and more frequently data. Under the cooperation of Meteorological Research Institute (MRI), JMA conducts D-InSAR using PALSAR-2 data around domestic active volcanoes and analysis results are used for the volcanic activity evaluation and judging eruption alert level such as the activation of Hakone volcano in 2015, the eruption of Kuchinoerabujima, the magma intrusion in Sakurajima (Secretariat of Satellite Analysis Group, Coordinating Committee for Prediction of Volcanic Eruption, 2016). In this presentation, we mainly report on the analysis results of the long-term pair (2014 to 2016.) around the domestic active volcanoes. The results were reported to Coordinating Committee for Prediction of Volcanic Eruption as well as the results of 2014 to 2015 (Ando, et al., 2016).
Some of PALSAR-2 data were prepared by the Japan Aerospace Exploration Agency (JAXA) via Coordinating Committee for the Prediction of Volcanic Eruption (CCPVE) as part of the project ‘ALOS-2 Domestic Demonstration on Disaster Management Application’ of the Volcano Working Group. Also, we used some of PALSAR-2 data that are shared within PALSAR Interferometry Consortium to Study our Evolving Land surface (PIXEL). PALSAR-2 data belongs to JAXA. We would like to thank Dr.Ozawa (NIED) for the use of his RINC software. In the process of the InSAR, we used Digital Ellipsoidal Height Model (DEHM) based on ‘the digital elevation map 10m-mesh’ provided by GSI, and Generic Mapping Tools (P.Wessel and W.H.F.Smith, 1999) to prepare illustrations.

Keywords: ALOS-2/PALSAR-2, InSAR, Domestic Active Volcano

Locally distributed crustal deformation in potential areas of phreatic eruptions detected by InSAR analyses

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Phreatic eruptions may be related to transient pressure changes in subsurface regions of hydrothermal systems attributing a heating of shallow aquifers from magma. It means that crustal deformation presumably proceeds with the pressure increase under the ground, which can be a kind of precursor if it would be detected. One of the most difficult points is that as the eruption size becomes smaller, the precursor signal should be more local, suggesting that it is rather hard to identify the anomaly using conventional ground-based observation tools. An effective proactive monitoring method for phreatic eruptions is desired, and one of the tools to overcome the drawbacks is SAR observation.

Hakone Owaku-dani: Inflational signal has been detected in a local area with a diameter of ~200 m by InSAR analysis, associated with the volcanic activity that started from the end of April, 2015. The distribution of the crustal deformation has a concentric pattern at the initial stage, but the location of the maximum displacement shifted southwestward although the spatial size has not changed. The small eruption occurred in the end of June at the location where the largest displacement was observed. The most important point for this event is that locally distributed crustal deformation has been successfully detected prior to the eruption, and the eruption did occur at the anomalous area. In Hakone volcano, there has been several remarkable volcanic activities since 2001. In this context, it is vital to investigate the crustal deformation at these activities to better understand the relationship between an eruption and such local deformation. Applying InSAR analysis to ALOS data for the 2008 activity, no significant signal can be identified in the Owaku-dani area. In 2001 and 2015, fumarole activities has increased outstandingly, while no significant anomaly of fumarolic activity can be identified in other activities. It is probably suggested that pressure increase associated with heat supply from the depth has not proceeded in the subsurface in the 2008 activity. I will report InSAR analysis results for other past activities.

Tateyama Midagahara (Jigoku-dani): Jigoku-dani area is known as an active geothermal area with fumarole and boiling water activity. In the past few years, geothermal activity on the ground has become more visibe with burning and flow out of sulfur in 2010 and increased temperatures of fumarole. Applying InSAR time series analysis to ALOS data, I detected locally distributed inflational deformation in the Jigoku-dani geothermal area. The deformation speed is estimated to be at about 4cm/yr at maximum. The deformation area is spatially consistent with the area where active fumarole and boiling water are seen on the ground. I additionally applied InSAR analyses to ALOS-2 data to investigate recent crustal deformation. The result shows that there appears no significant deformation in these two years. The geothermal activity is still in high-level, but the state is relatively stable in time. These SAR observation results probably suggest that no significant pressure change has proceeded in the geothermal system at shallow.

Anomalies observed on the ground surface such as fumarolic activity is thought to be directly related with the state change of the geothermal system. It seems that there is a good correlation between the SAR-derived local crustal deformation and the geothermal anomaly on the ground. It is suggested that the InSAR-derived deformation data can be a kind of indicators exploiting the state of pressure under the ground, and can extract some physical parameters related to phreatic eruptions. In this presentation, in addition to above-mentioned cases, I will show some local ground inflational signals observed in geothermal areas where eruptions have not occurred as yet.

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Keywords: phreatic eruption, InSAR, local crustal deformation

Estimation of viscosity of erupting magma from lava flow morphology

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Eruption types of volcanoes depend on magma viscosity. For example, in the case of magma with much volatiles, viscous magma causes Plinian eruption, and conversely magma with low viscosity causes Hawaiian eruption which forms lava fountain. Thus, in studying volcanic eruptions, it is meaningful to investigate viscosity of erupting magma.
Viscosity of lava flow varies according to various factors like temperature (Minakami et al., 1951) and petrologic compositions (Shaw, 1972). In this study, we focus on lava flow morphology formed by volcanic eruptions, and aim to establish a method for estimating viscosity and to calculate viscosity of erupting lava flow from various volcanoes. The merit of this morphological method is that it requires no direct observation data such as flow rate or temperature, so it can apply to various lava flows erupted in the past.

The method of calculating viscosity from morphological parameters of lava flow such as thickness and width is presented by Stevenson et al. (1994). Firstly, we used lava flow simulation offered by Earthquake Research Institute (Yasuda et al., 2013) to evaluate the utility of this method. This simulation uses the method presented by Ishihara et al. (1990). We determined morphological parameters from the simulation results, calculated viscosity using Stevenson’s formula, and then compared with original value calculated from erupting temperature using Minakami’s formula. As a result, values obtained from Stevenson’s method showed different distribution from the original values’. Also, it proved that this method cannot calculate because of error when assumed viscosity was too high.
We used a new method to estimate viscosity in order to solve the above problem. This time, we adopted aspect ratio which can be obtained by dividing lava flow thickness by the square root of its area size. We calculated aspect ratio from the simulation result, and then derived a relation among the ratio, gradient of the ground, and original viscosity calculated from erupting temperature. We also applied this relation to real lava flow topography and ascertained its usefulness. Although the verification is not enough, this method of aspect ratio is expected to be applied to various places because it can obtain significant results regardless of lava flow characteristic or gradient of the ground.

Keywords: lava flow, magma, viscosity, aspect ratio

Numerical study on the onset of explosion earthquakes

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Vulcanian eruption is characterized by sudden ejection of volcanic fragments, excitation of shock wave, and explosion earthquake. Analysis of explosion earthquakes provides us important features to understand the source dynamics of Vulcanian eruptions. A number of previous studies reported that the polarity of the onset of explosion earthquakes is compressional at all stations (e.g., Minakami, 1960). The focal depth of explosion earthquakes is usually estimated at several km beneath the active vent (e.g., Imai, 1980). Observed waveforms of explosion earthquakes are explained by volume change (e.g., Tameguri et al., 2002) or vertical single force (e.g., Ohminato et al., 2006). However, the source mechanism obtained from inverse analysis of observed waveforms represents macroscopic force system at the source region. It is still challenging to infer the dynamics in the volcanic conduit from seismic analysis.

Magma fragmentation and ejection of volcanic material accompanying Vulcanian eruptions are often modeled by the shock tube theory (e.g., Woods , 1998). To obtain fundamental characteristics of explosion earthquakes, we examine displacement field induced by the shock tube problem in a vertical elastic pipe. We adopt OpenFOAM to calculate fluid-solid interaction (FSI). Since the original version of FSI solver in OpenFOAM(foam-extend 3.0) can handle incompressible flow only, we modify the solver to calculate the interaction between compressible flow and elastic media. For simplicity, the fluid in the elastic pipe is assumed as ideal gas. The elastic pipe has 20 m radius and 4 km length. The elastic media surrounding the pipe is set for 4 km from the pipe. The depth of a diaphragm of shock tube is assumed at the focal depth of explosion earthquakes at some volcanoes. We set the pressure difference at the diaphragm in the pipe referring estimated overpressure of Vulcanian eruptions by previous studies. In the pipe, high pressure region is assumed beneath the low pressure region as the initial condition.

The result of our numerical simulation shows that compressional displacement field is induced in the elastic media at the depth where the pressure in the pipe has increased. Contrary, dilatational displacement field is seen at the depth where the pressure in the pipe has decreased. The elastic wave propagates from fluid-solid boundary at the depth of the diaphragm. The polarity of the onset of elastic wave has a nodal plane about 30° upward from the horizontal plane. The elastic wave propagating above the nodal plane show the compressional polarity. Therefore, the displacement waveforms at the surface of elastic media near the pipe show the compressional onset. On the other hand, since the nodal plane across the ground surface, displacement waveforms at far side from the pipe have the dilatational onset. The pressure change in the pipe below the diaphragm (pressure decreasing) is almost twice of that above the diaphragm (pressure increasing). Therefore, the angle of the nodal plane of the polarity may reflect the pressure change in the pipe.

We compare the result of numerical simulation and features of explosion earthquakes at Lokon-Empung volcano (Yamada et al., 2016). Yamada et al. (2016) reported that the focal depth of explosion earthquakes is about 1 km beneath the active vent. The polarity of the onset of explosion earthquakes are compressional at all stations, ranging 1.7-6.9 km from the active vent. Our numerical simulation shows that the compressional onset is seen at the region near the pipe (< 1.5 km), assuming the diaphragm as 1 km beneath the surface. Contrary, the compressional onset cannot be seen at far side region (> 1.5 km) from the pipe. Therefore, it is suggested that additional source process has to be considered to reproduce the initial compressional wave at all stations. The ejection of volcanic fragments accompanying Vulcanian eruptions lasts only about several tens of seconds, Therefore, it is regarded that the fragmentation process of Vulcanian eruptions also has the same range of duration. Since the fluid in the pipe is assumed as ideal gas, the process that terminates the eruption is not considered in our numerical simulation. Taking into account this process will be valuable to examine the entire characteristics of observed waveforms.

Keywords: Vulcanian eruption, shock tube, OpenFOAM

A generalized equation for the resonance frequencies of a fluid-filled crack

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Although a model of the resonance of a rectangular fluid-filled crack (crack model; Chouet, 1986, JGR) is one of the most frequently used source models of long-period (LP) seismic events at volcanoes, there has been no analytical solution for the resonance frequencies. We previously proposed an empirical expression for the resonance frequencies (Maeda and Kumagai, 2013, GRL):
$f_m = (m - 1)a/\{2L_x[1 + 2\varepsilon_m C_x]^{1/2}\}$, (1)
where a is the sound velocity of the fluid, L_x is the crack length along the wave propagation direction, m is the mode number defined such that the wavelength is $2L_x/m$, C_x is the crack stiffness, and ε_m is an empirical constant that depends on the crack aspect ratio χ and oscillation mode m. Although eq. (1) can potentially be used to compute the resonance frequencies easily, the requirement to determine the value of ε_m numerically for each crack aspect ratio and oscillation mode has prevented widespread use of the equation for interpretations of LP events at volcanoes.

In the present study, we examined the theoretical basis for the expression. We assumed that the ratio of the crack wall displacement to the fluid pressure near each crack edge varied as the square root of the distance from the edge. Using this assumption, we showed theoretically that eq. (1) was a good approximation (difference 2%) to another more complete expression:
$f_m = (m - 1)a/(2L_x I_m)$, (2)
$I_m = (1 - 4\gamma/5m)J_m(g_{m0}C_x) + (16\gamma/15m)[1/K_m(g_{m0}C_x) + 1/K_m(g_{m0}C_x)^2]$, (3)
where $J_m(\xi) = (1 + 2\xi)^{1/2}$, $K_m(\xi) = J_m(\xi) + 1$, $\gamma = 0.22$, and
$g_{m0} = (1 - 4\gamma/3m\chi)/(3m - 4\gamma)$ (4)
for $\chi > 4\gamma/m$ and
$g_{m0} = (2/3)(m\chi/4\gamma)^{1/2}/(3m - 4\gamma)$ (5)
for $\chi < 4\gamma/m$. The constant g_{m0} in eqs (4) and (5) is related to ε_m in eq. (1) as $\varepsilon_m = g_{m0}(3m - 4\gamma)/(3m)$.

This theoretical expression (eqs 2-5) is a closed form of a mathematical function of the crack model parameters and oscillation mode number; there are no empirical constants to be determined numerically. The expression thus enabled us to analytically compute the resonance frequencies for arbitrary rectangular cracks, and the results were in good agreement (difference 5%) with numerical solutions. Resonance frequencies of cracks can be very easily predicted using this expression. This predictive ability may enhance our quantitative understanding of the processes that generate LP events at volcanoes.

Keywords: LP event, Resonance, Crack

Analysis of sound generated by the vibration of a bubble film

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Introduction
Bubble sounds have been measured with active degassing at volcanoes and used to estimate the gas flux (Vergniolle and Brandeis, 1996; Johnson et al., 2008; Bouche et al., 2010). The estimation assumes a specific mechanism of generating bubble sounds. However it is challenging to distinguish the specific mechanism from other possible mechanisms in the acoustic data observed at volcanoes. Here we investigate the characteristics of bubble sounds and a sound generating mechanism in laboratory experiments.

Experimental method and observations
It has been reported that bubble sounds differ by fluid rheology. We follow the experiments by Lyons et al. (2013) which used a viscoelastic transparent gel. Bubbles rise in the fluid with coalescence and oscillation, and finally escape from the fluid surface. The sequences are recorded by microphones and a high speed camera.
We find two main processes generating sound: (1) bubble detaching from a nozzle and (2) rising bubble above the fluid surface. In this experimental model, no sound signal is detected with bubble bursting. We focus on the signals generated by (2), because they are clearly distinguished from other signals and noise due to the following particular features.
The features about sound frequency: the sound frequency glides to the higher. The features about sound amplitude: the envelope has a spindle shape with the maximum mostly occurring when about a half to 2/3 of the bubble is on the surface. The amplitude is not always proportional to the radius of a bubble. Sudden damping occurs after the maximum amplitude, which is sometimes caused by drops touching the film of bubble. When the bubble bursts, the amplitude decreases quickly. The signal is very weak when a bubble bursts earlier. The amplitude is significantly large when an oscillation of bubble is excited before it appears on the surface.

Model Calculation
Here we call ‘head’ as the part of bubble on the fluid surface, ‘tail’ as the part below the surface. The bubble behaviors are separated into the three time parts: (A) the head rising, (B) the head absorbing the tail, and (C) the shape being settled.
In the focused process, the sound is generated by vibration of the head. Referring to Verginiolle and Brandeis (1996), who discussed the same mechanism, we formulate the vibration equation of a spherical shell with adding an internal excitation term due to the increase of the head radius. The radial motion the head is converted to the far-field acoustic wave (Blackstock, 2000), of which waveforms are similar to the experimental observation.
Both amplitudes of the radial oscillation of the head and acoustic wave grow when the radius of head is increasing in (A) and (B) and is damped in (C). Then, the spindle-shaped envelope of the signal is reproduced.
Incorporating the head and tail change with the model enables the oscillation to start without an external excitation. When an external excitation is initially given, the amplitude becomes larger without changing the waveform.
The followings are suggested by model. A bubble needs an excitation under the surface to generate a

sufficiently large acoustic signal on the surface.
The controlling factor of the frequency gliding is the ratio between the volume of the head and the tail in (A), the radius of the head in (B), and the film thickness in (C).

Discussion and Future Tasks
We discuss whether we can estimate the bubble volume using the sound of the focused mechanism. The amplitude is not useful because it is significantly affected by the condition of the head of bubble and external excitation. The upward gliding frequency is the feature used to identify this mechanism. The beginning of the frequency change is controlled by the radius of the head so that it is potentially useful to estimate the bubble volume.

Keywords: bubble, sound, volcano

